IGS-related multi-GNSS activities at CODE

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CODE: who we are?

- CODE = Center for Orbit Determination in Europe
- joint venture between
  - Astronomisches Institut der Universität Bern (AIUB)
  - Bundesamt für Landestopographie swisstopo
  - Bundesamt für Kartographie und Geodäsie (BKG)
  - Institut für Astronomische und Physikalische Geodäsie, TU München (IAPG, TUM)
- operational since 1992, located at the University of Bern
- contributions to all product lines of the IGS from a rigorous multi-GNSS processing (also contributing to the EPN and ILRS)
- all products are generated using the *Bernese GNSS Software* developed and maintained by the AIUB

Outline

1. Introduction: IGS-MGEX
2. CODE-MGEX orbit solution
3. CODE-MGEX clock solution
4. PPP
5. Summary and outlook

IGS: Internation GNSS Service

- IGS-MGEX: IGS Multi-GNSS Experiment
- **Scope:** (from www.igs.org/mgex)
  *The Multi-GNSS Experiment (MGEX) has been set-up by the IGS to **track, collate and analyze** all available GNSS signals. This includes signals from the BeiDou, Galileo and QZSS systems, as well as from modernized GPS and GLONASS satellites and any space-based augmentation system (SBAS) of interest. Analysis centers will attempt to estimate inter-system calibration biases, compare equipment performance and further develop processing software capable of handling multiple GNSS observation data.*

IGS MGEX history

- Call for Participation in August 2011
- Start of the project in February 2012
- First results have been exchanged at the IGS workshop in Olsztyn, Poland (end of July 2012).
- In important update is expected at the next IGS workshop in Pasadena, USA (end of June 2014).

- Further information about MGEX:
  Montenbruck O., Steigenberger P., Khachikyan R., Weber G., Langley R.B., Mervart L., Hugentobler U., "IGS-MGEX: Preparing the Ground for Multi-Constellation GNSS Science", InsideGNSS 9(1):42-49 (2014).

IGS-MGEX network (from www.igs.org/mgex)

Network

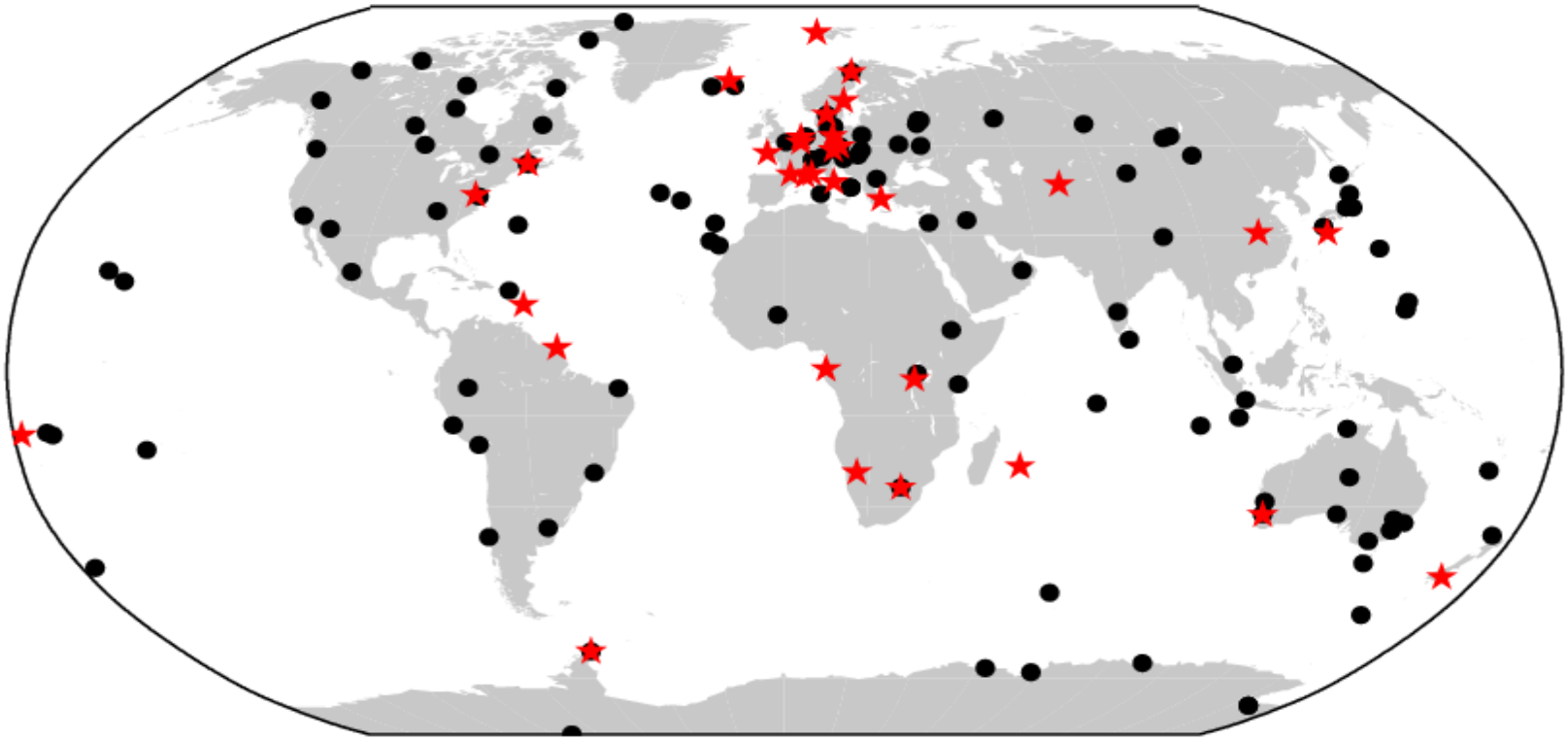
An overview of the current MGEX network is shown in the map below. For detailed information on individual stations see the MGEX station list. The latetst site logs are available from the IGS MGEX site log archive.

The CODE MGEX solution

- All available Galileo tracking stations are included. (Some selection is only done in Europe.)
- The network is completed by the GPS+GLONASS tracking sites typically used in the CODE rapid solution for the IGS (about 120 stations).
- **CODE MGEX solution is rigorous triple-system solution with GPS+GLONASS+Galileo.**
- *Important note*:
  The CODE MGEX solution is updated in batches – no operational processing. Each batch is carefully studied before the publication; next steps for the development is derived from this evaluation.

CODE MGEX solution: station selection

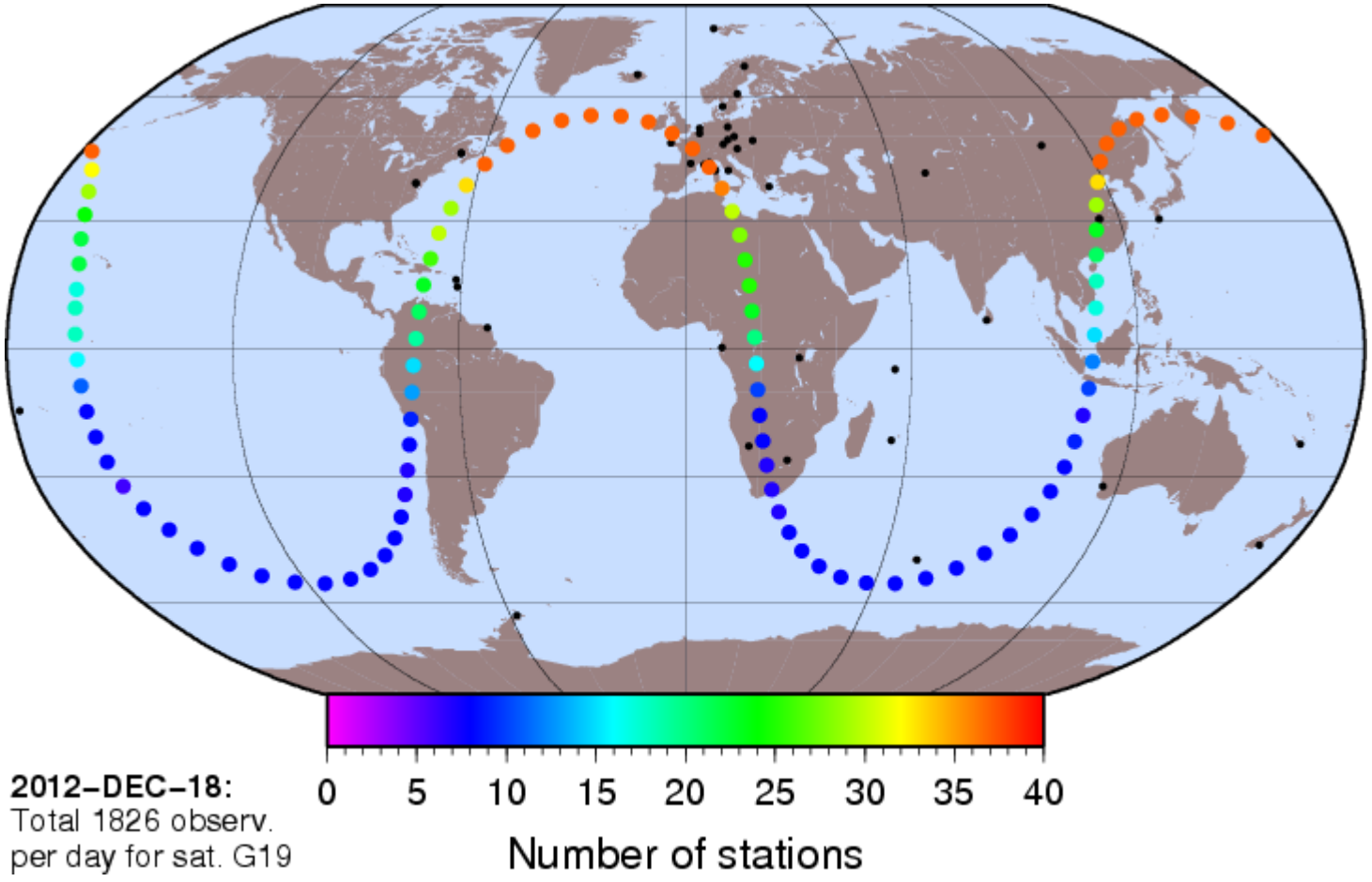
Number and distribution of tracking stations
contributing to the CODE MGEX orbit solution (*late 2012*)



Num. of stations:	GPS: 145–150	GLONASS: 125	Galileo: 30–35
Num. of observ. per sat. and day	22,000–25,000	18,000–20,000	1,500–5,000

CODE MGEX solution: ground tracks

Number of MGEX stations tracking: G19



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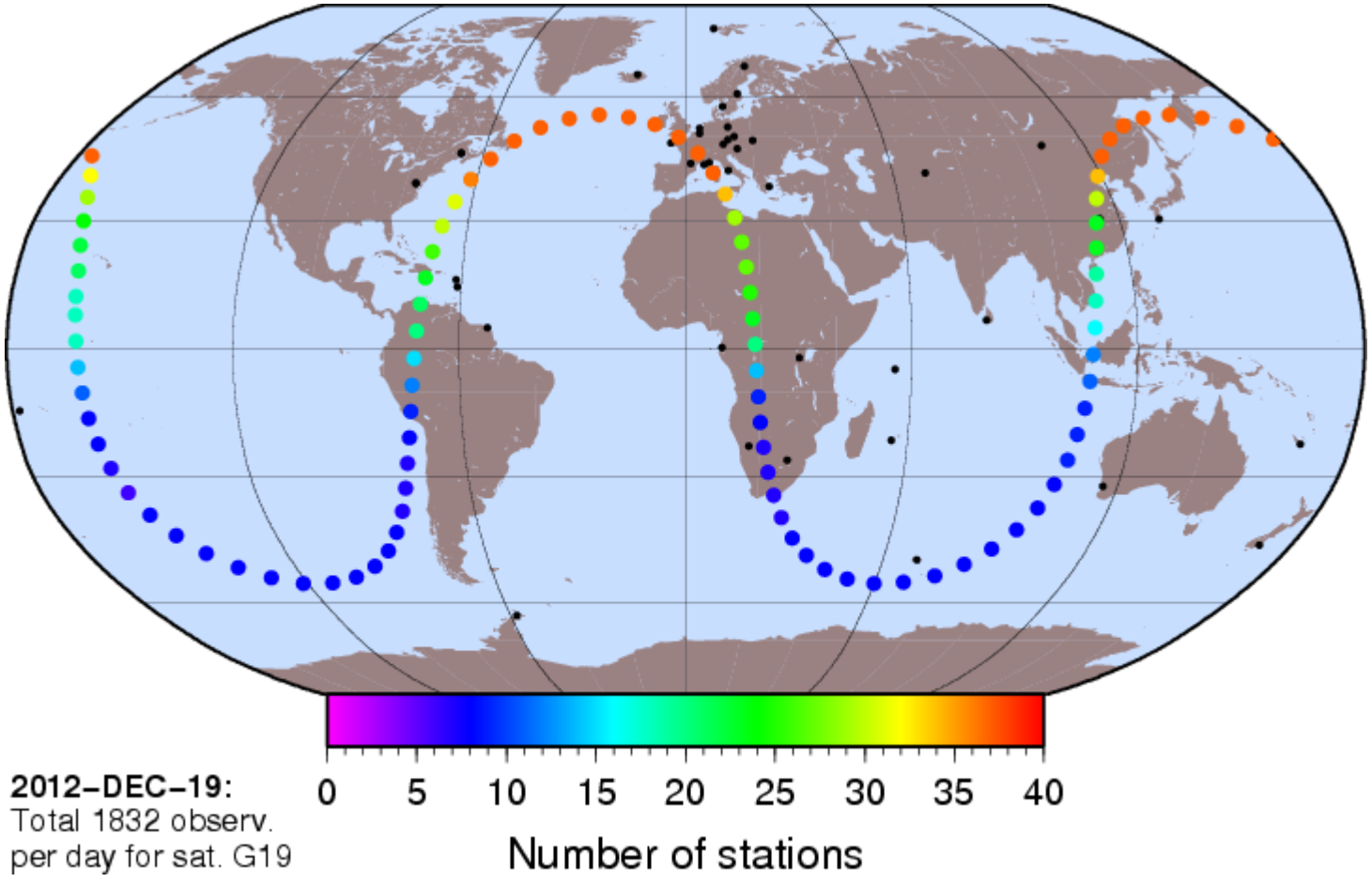

CODE MGEX solution: ground tracks

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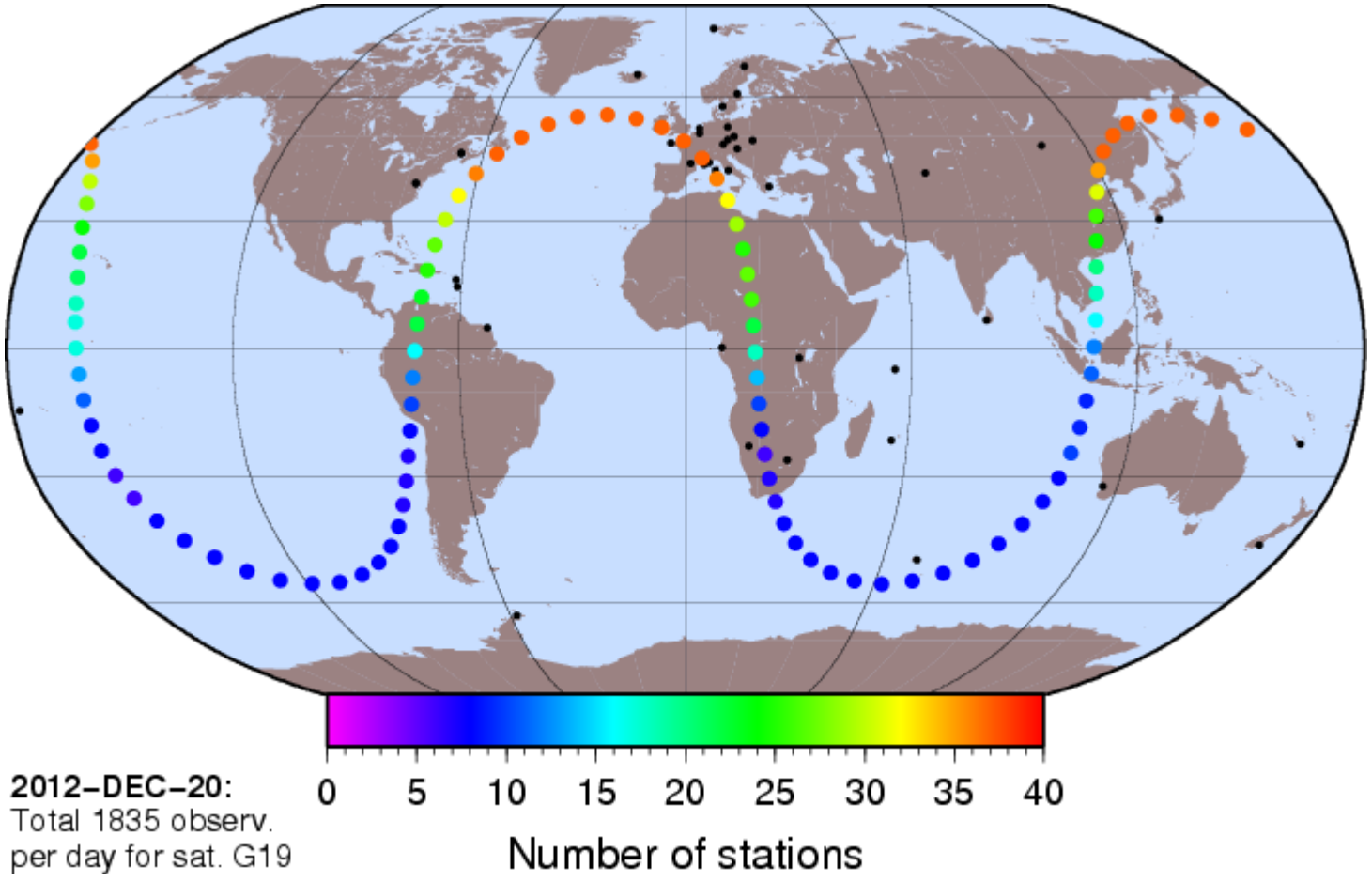
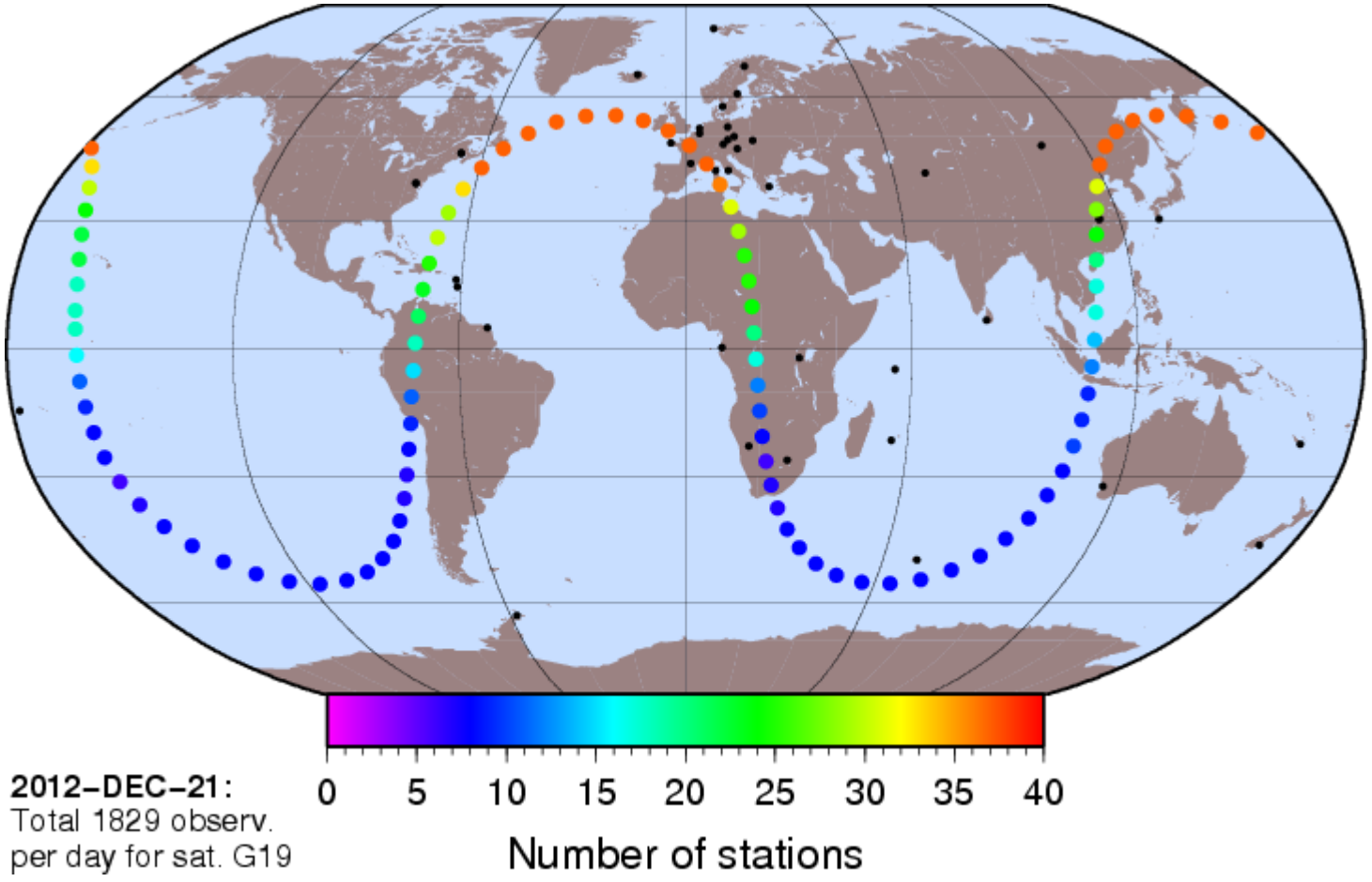


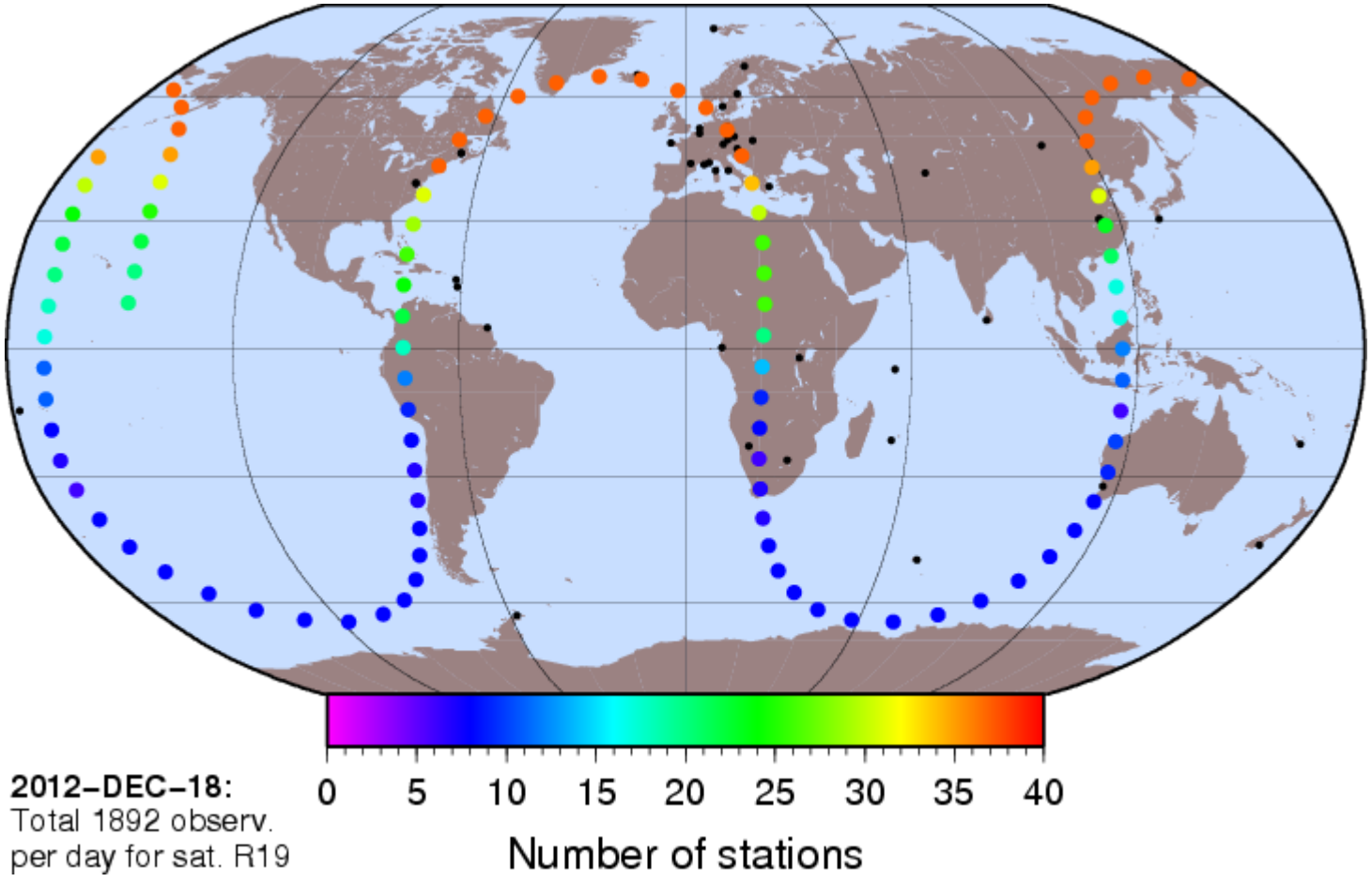
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: G19



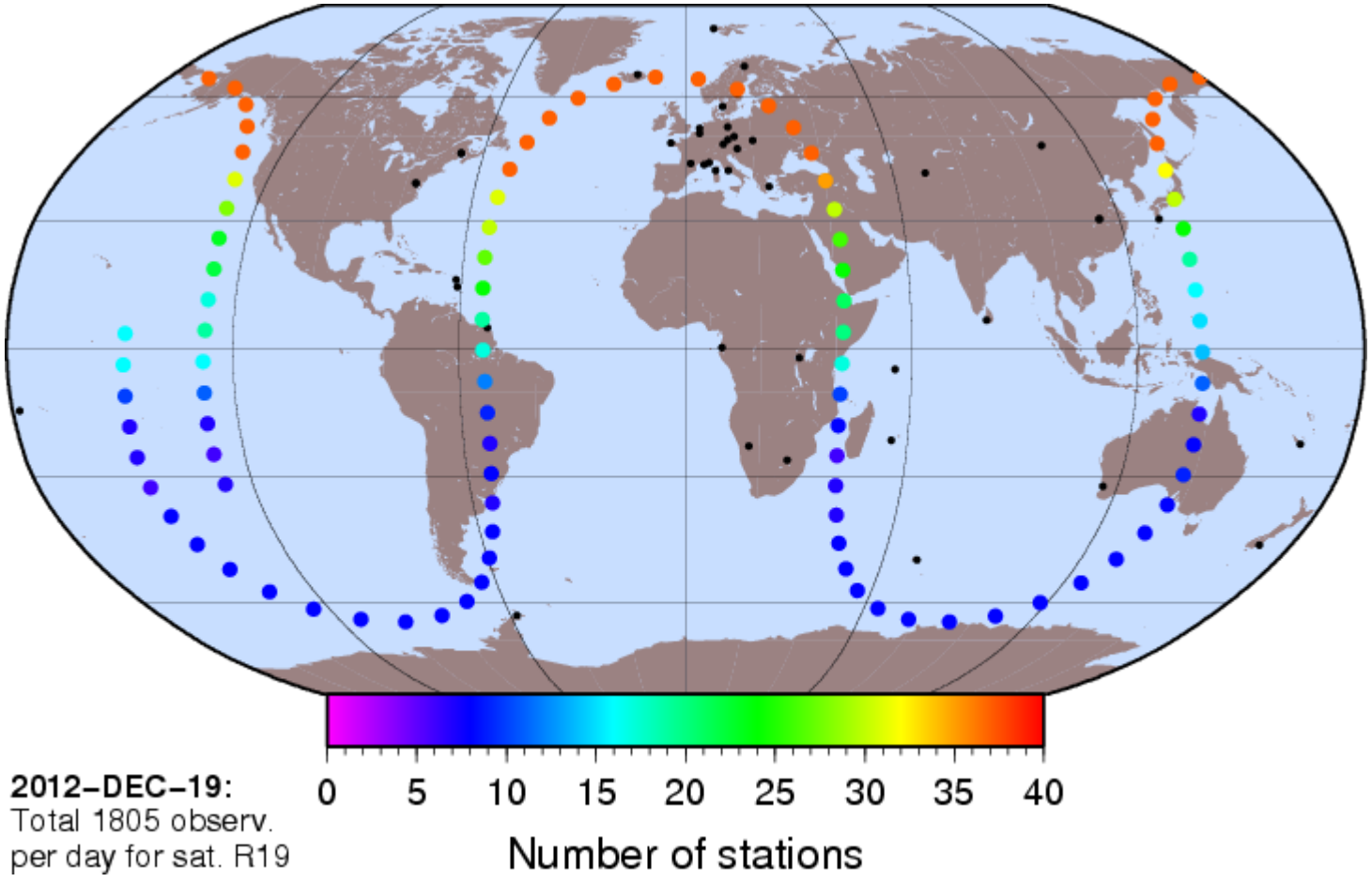
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: R19



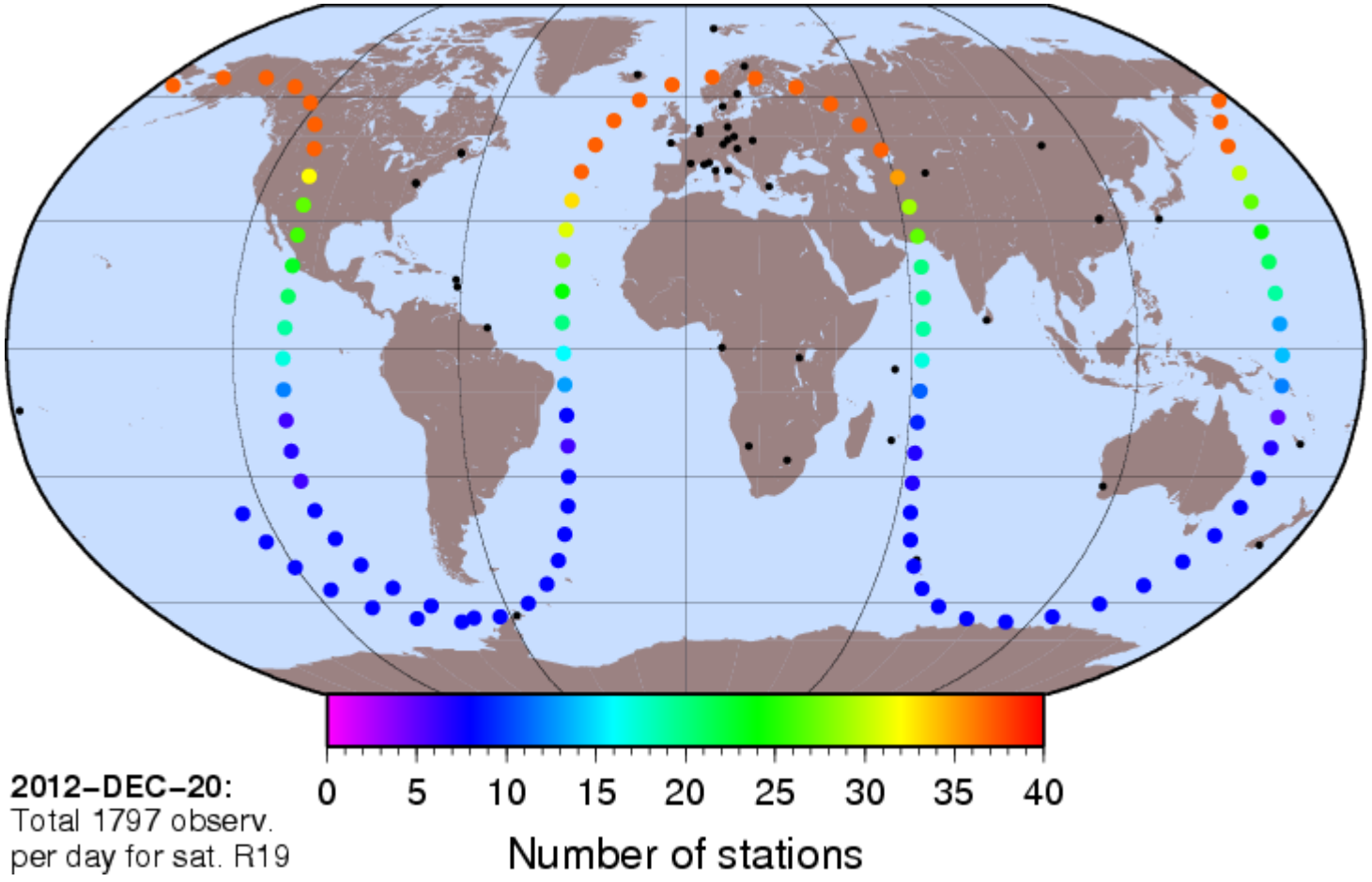
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: R19



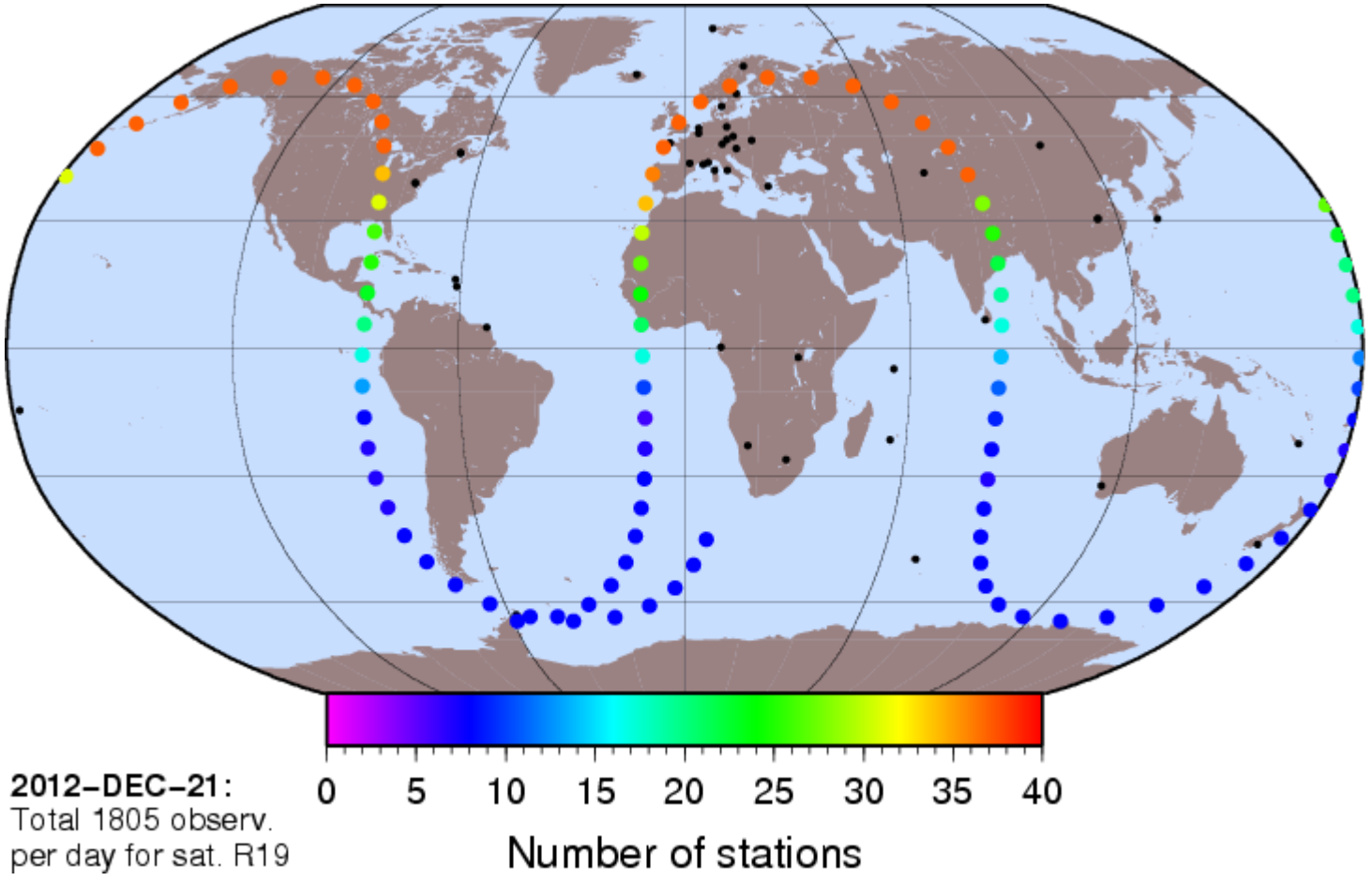
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: R19



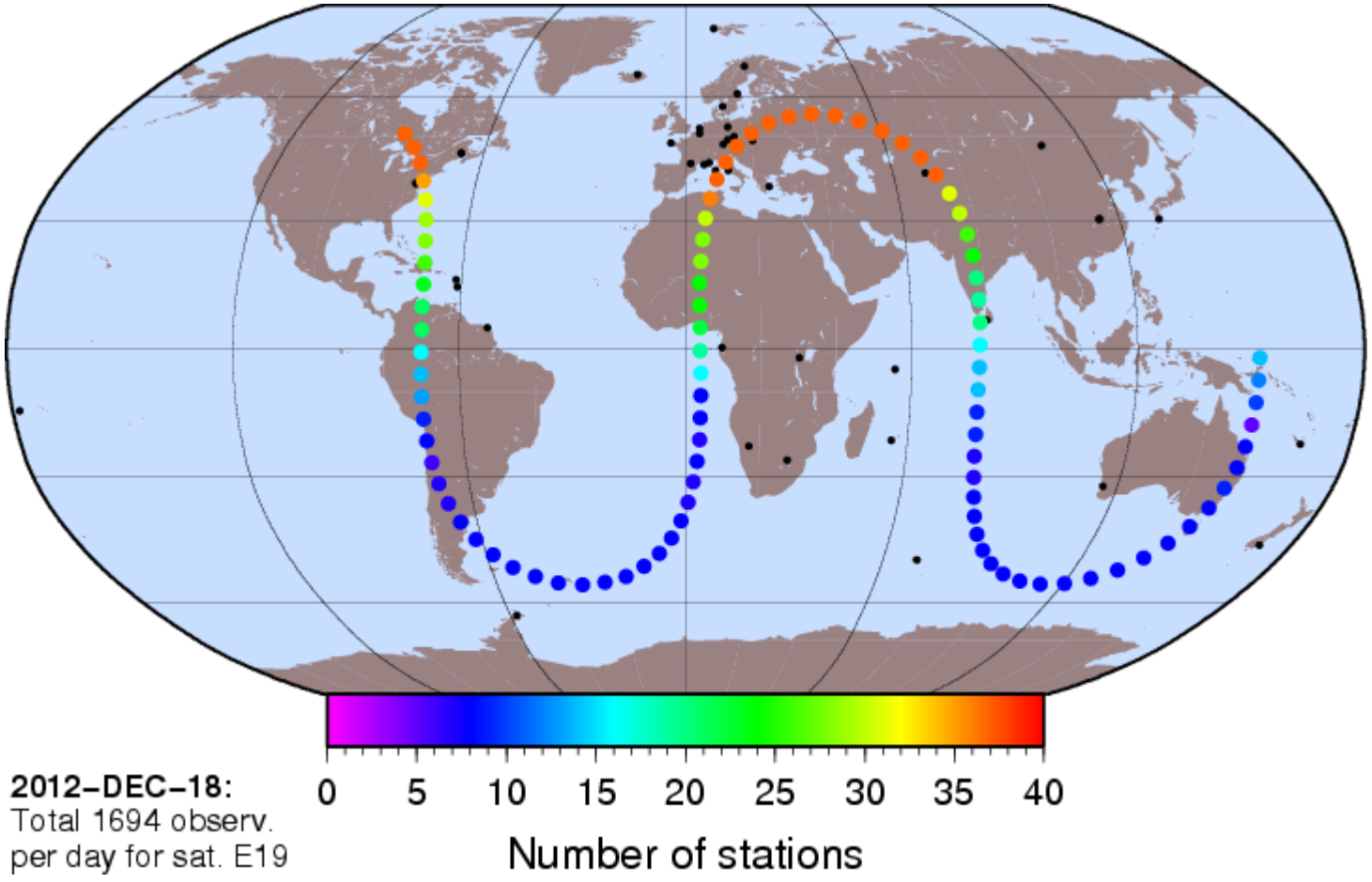
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: R19



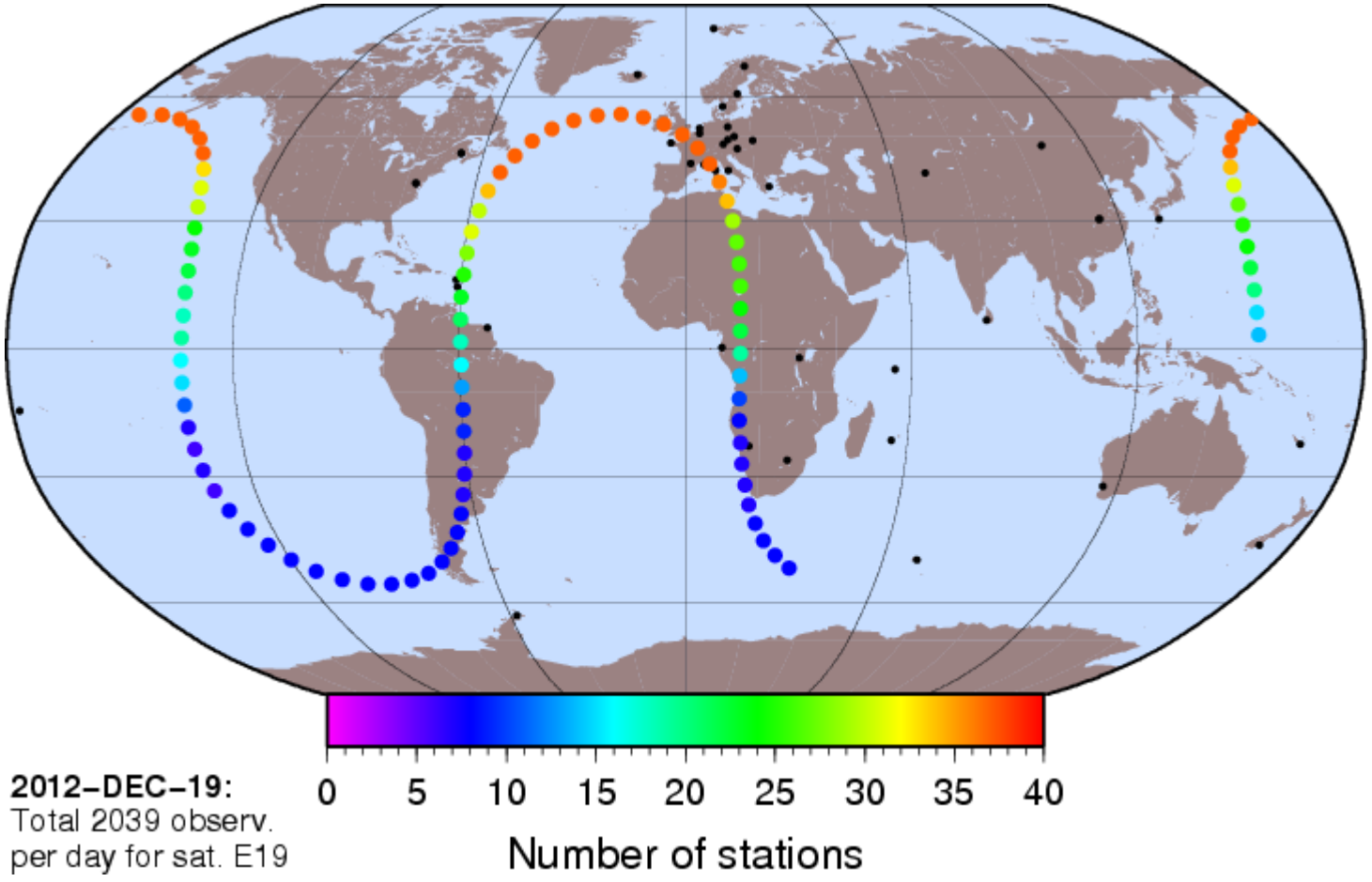
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: E19



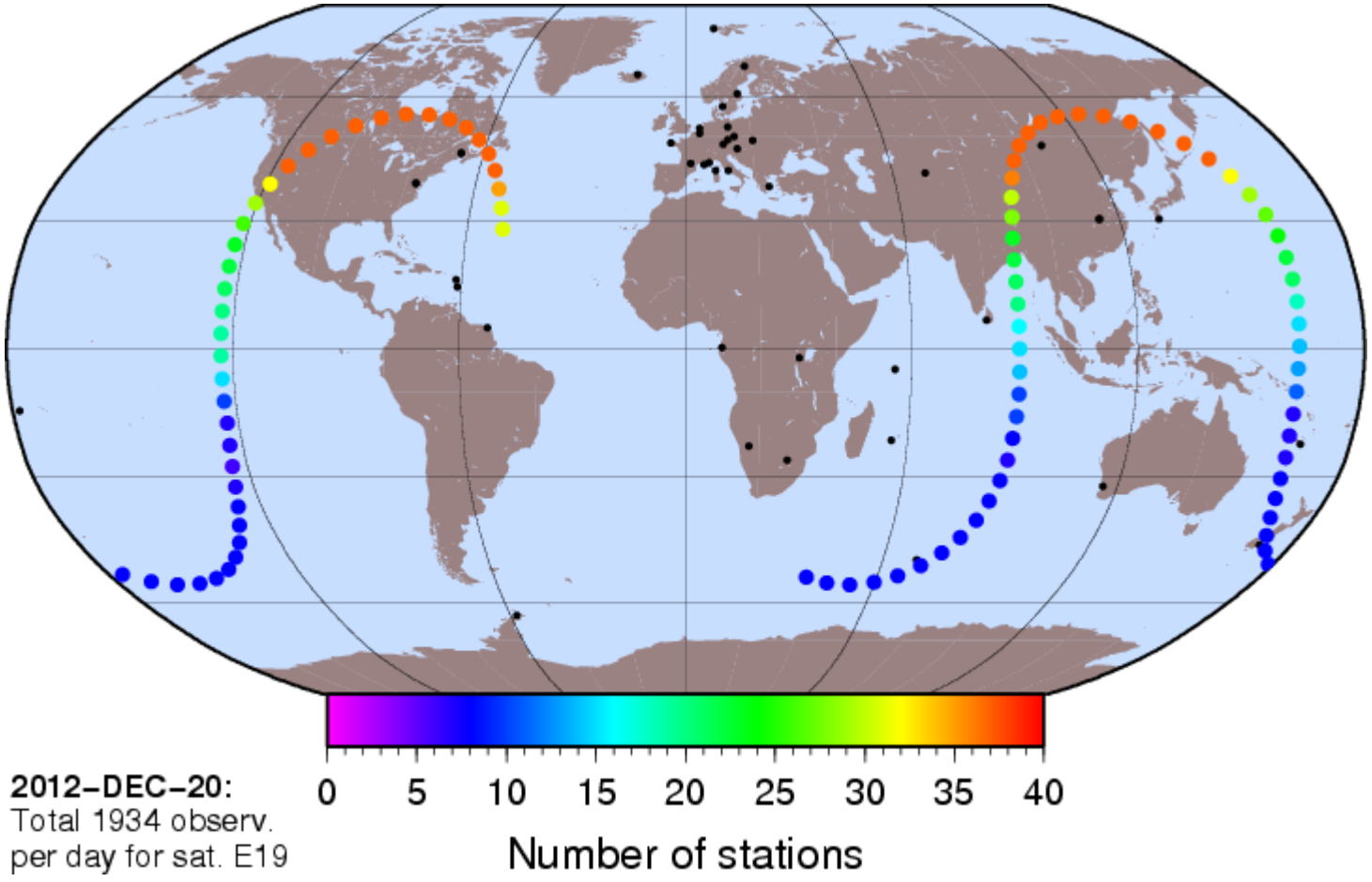
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: E19



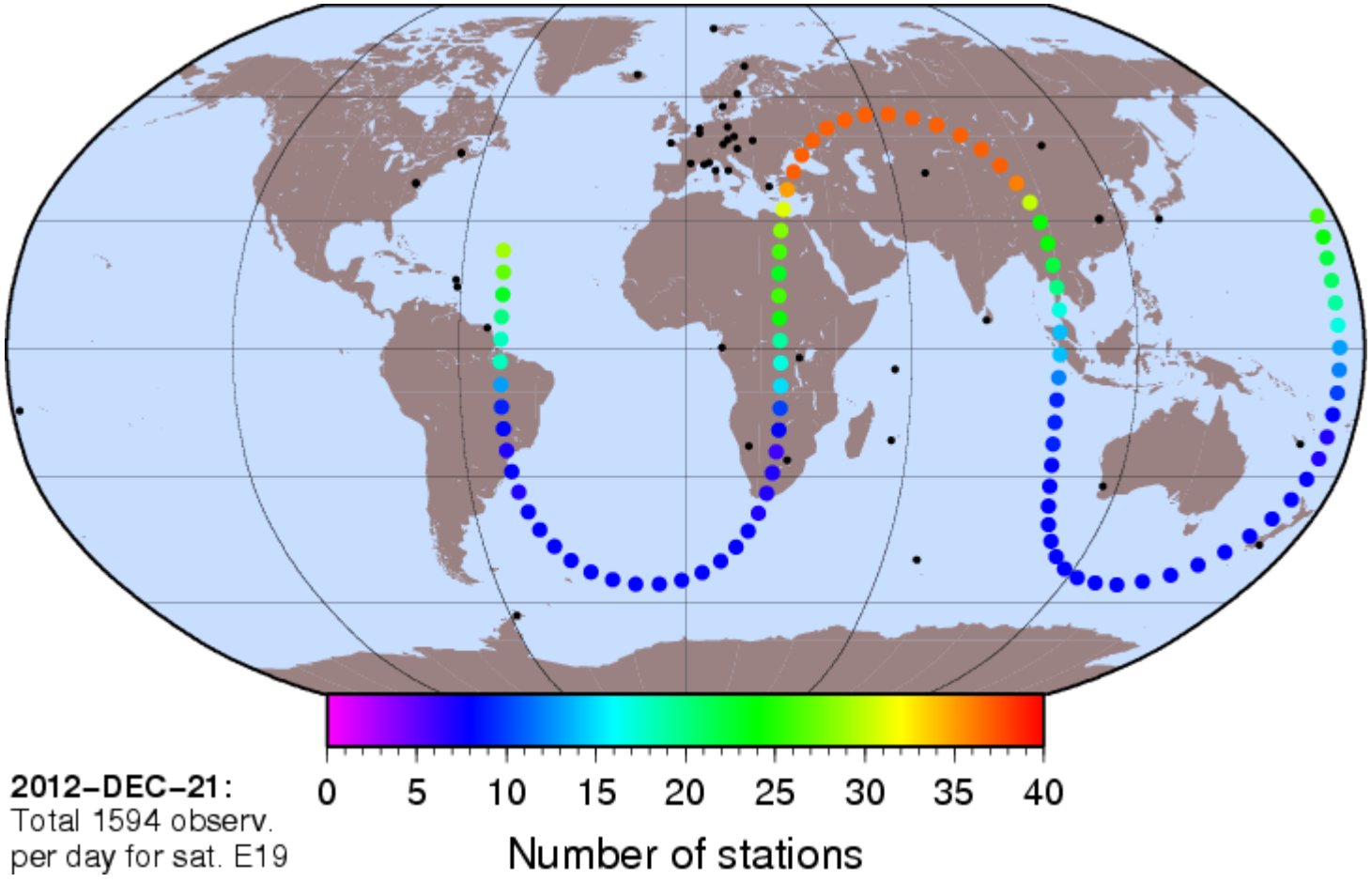
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: E19



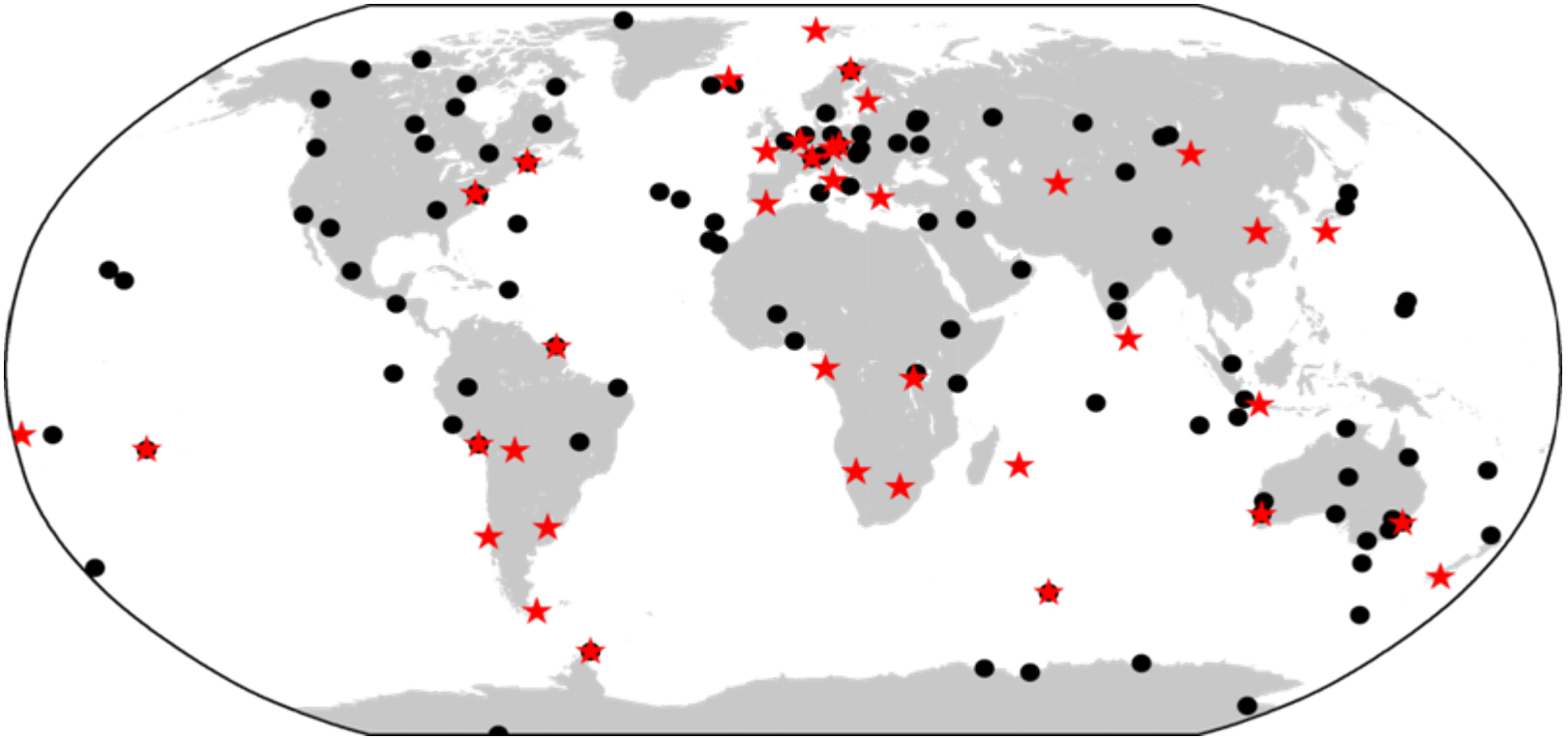
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: E19



CODE MGEX solution: station selection

Number and distribution of tracking stations
contributing to the CODE MGEX orbit solution (*mid 2013*)



Num. of stations:	GPS: 145–150	GLONASS: 125	Galileo: 30–40
Num. of observ. per sat. and day	22,000–25,000	18,000–20,000	4,000–6,500

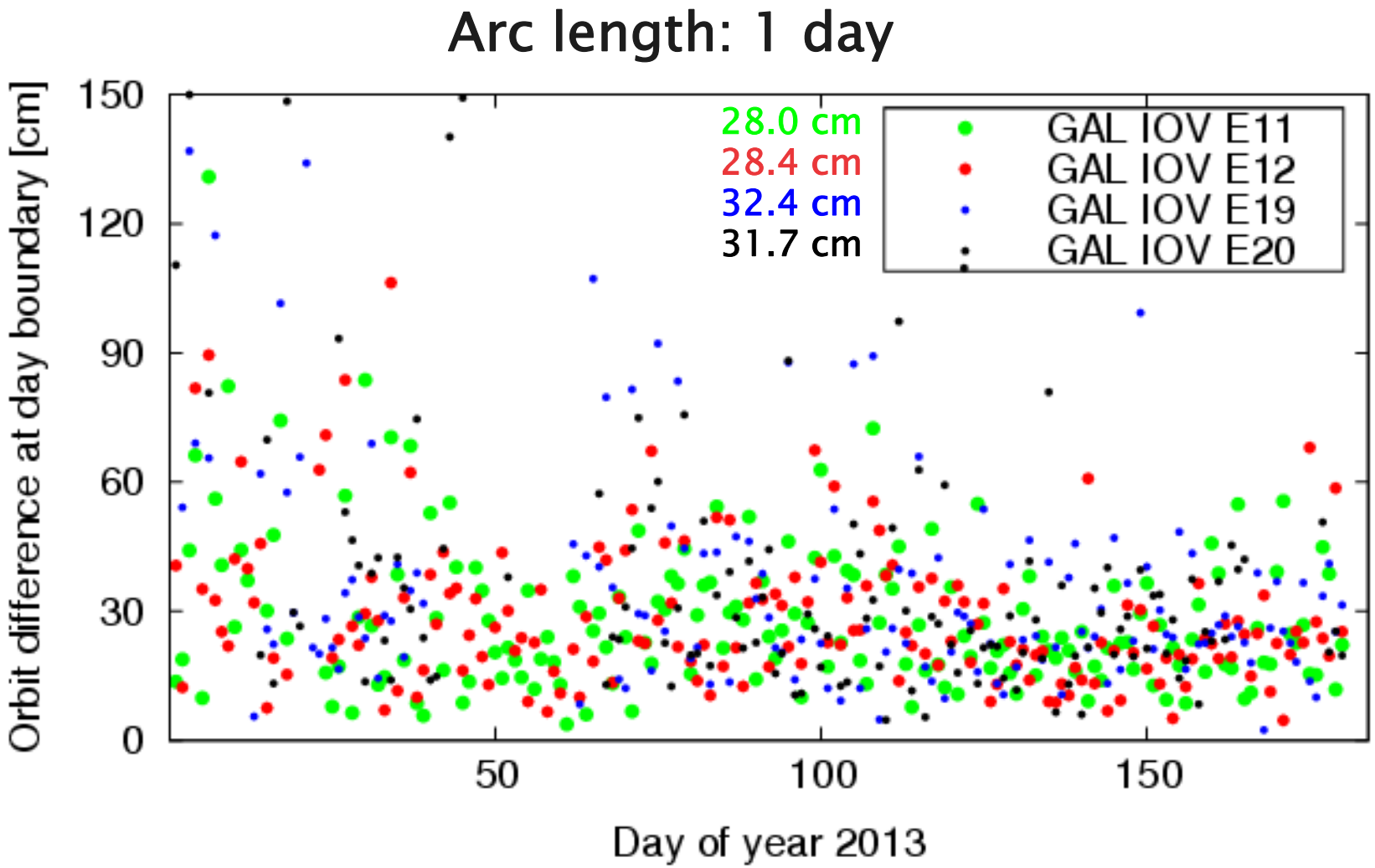
CODE MGEX orbit solution: overview

GNSS considered:	GPS + GLONASS + Galileo (up to 60 satellites)
Processing mode:	post-processing
Timespan covered:	GPS-weeks 1689-1746 (DOY 12/146-13/180)
Number of stations:	150 (GPS + GLONASS), 30 - 40 (Galileo)
Processing scheme:	double-difference network processing (observable: phase double differences)
Signal frequencies:	L1+ L2 (GPS + GLONASS), E1 (L1) + E5a (L5) (Galileo)
Orbit characteristic:	3-day long arcs
Reference frame:	IGS08 (until week 1708); IGb08 (since week 1709)
IERS conventions:	IERS2003 (until 1705); IERS2010 (since 1706)
Product list:	daily orbits (SP3) and ERPs
Distribution:	ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/
Designator:	comwwwwd.???.Z

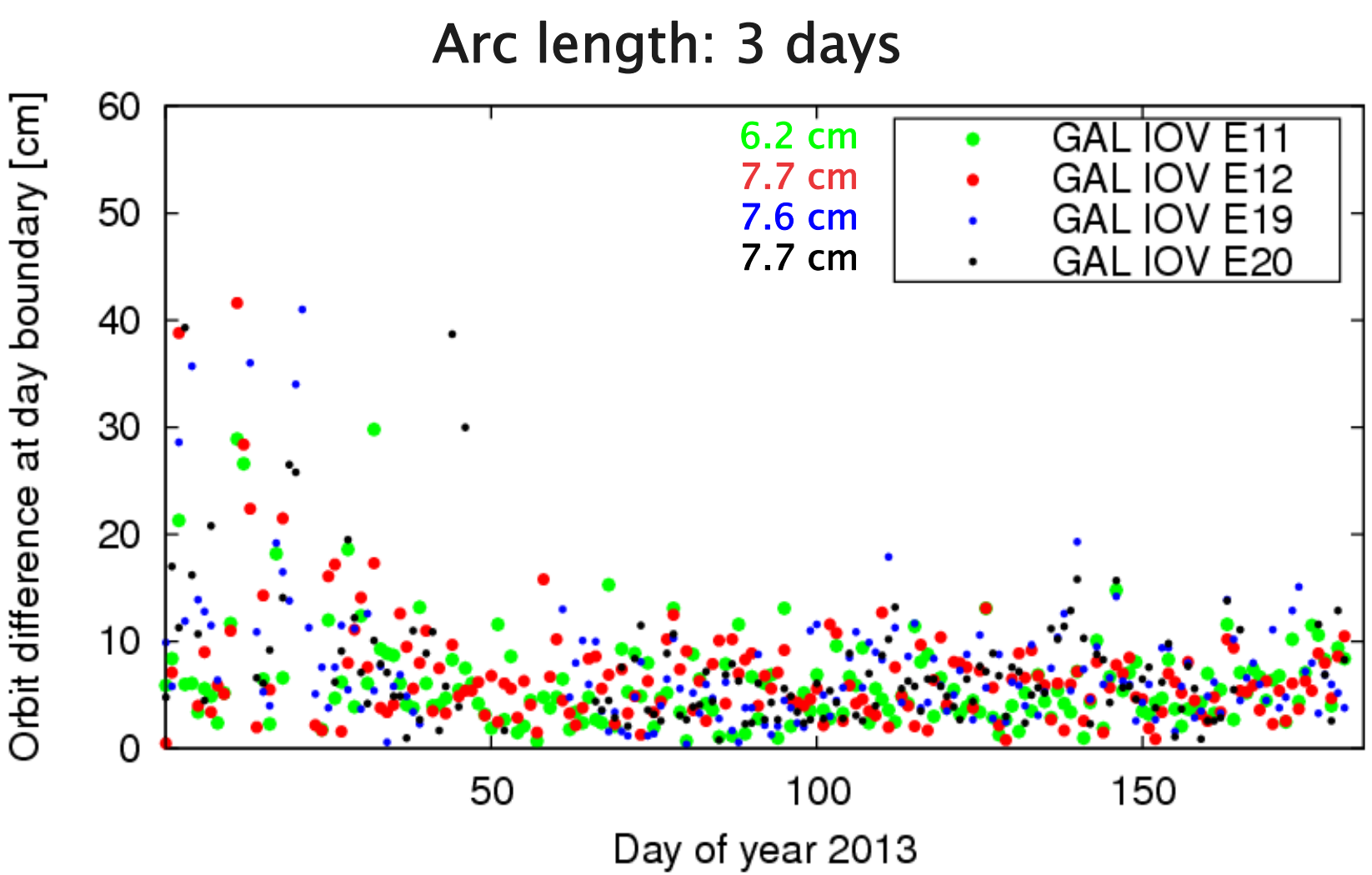
Methods for orbit validation

1. Orbit overlaps

Orbit validation: overlaps

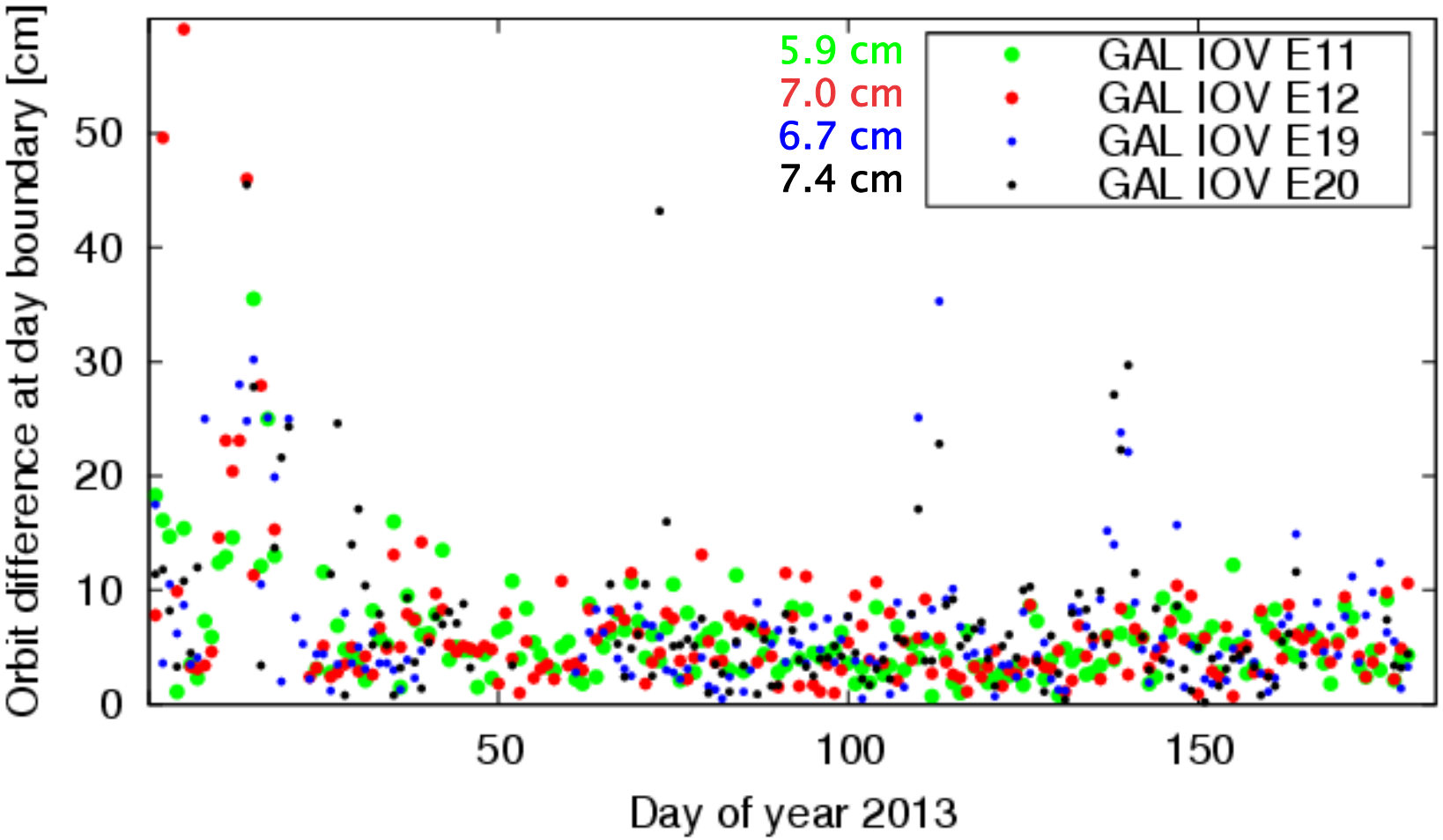


Orbit validation: overlaps



Orbit validation: overlaps

Arc length: 5 days

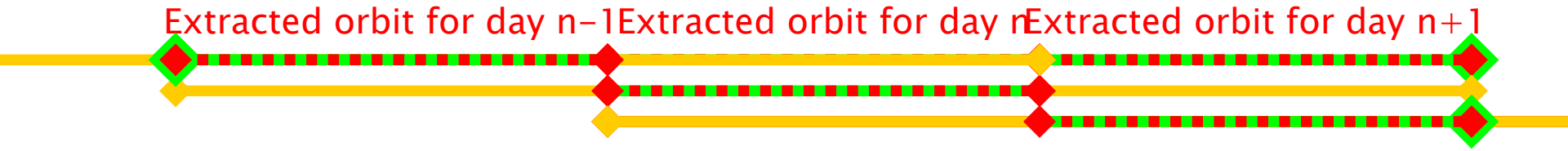


Methods for orbit validation

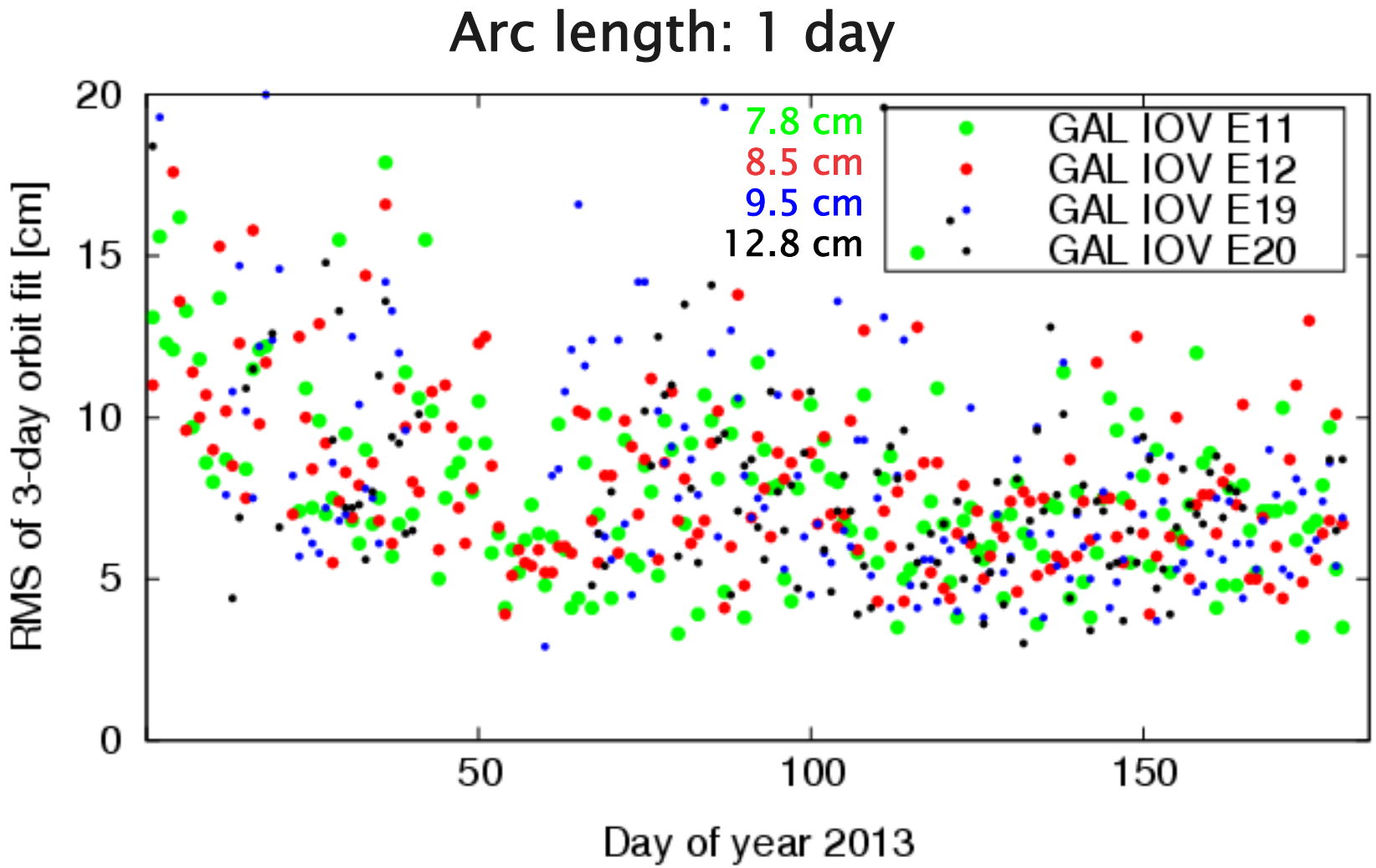
1. Orbit overlaps

2. Fitting long-arcs

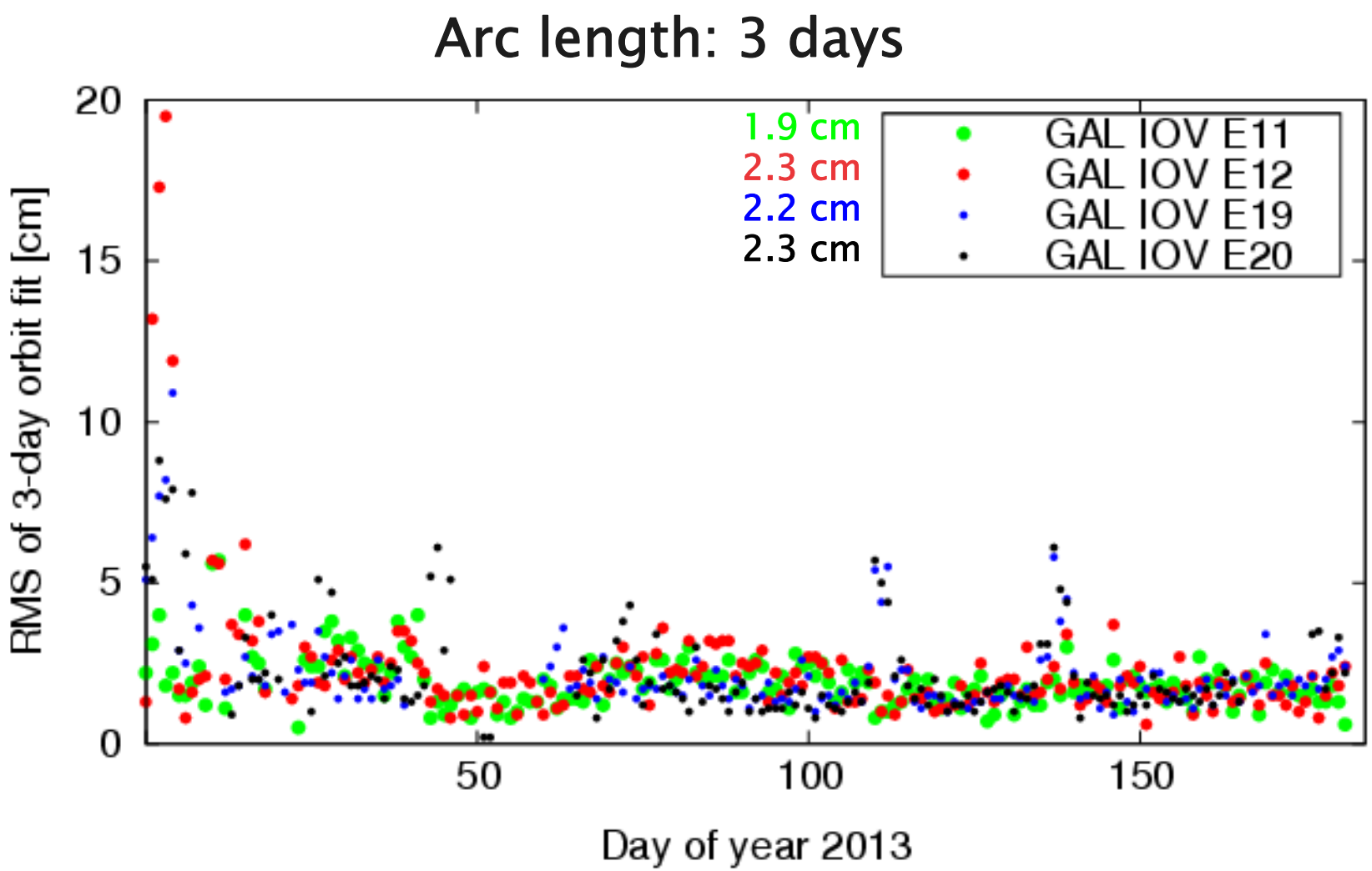
- *Remark on multi-day arc solution:*



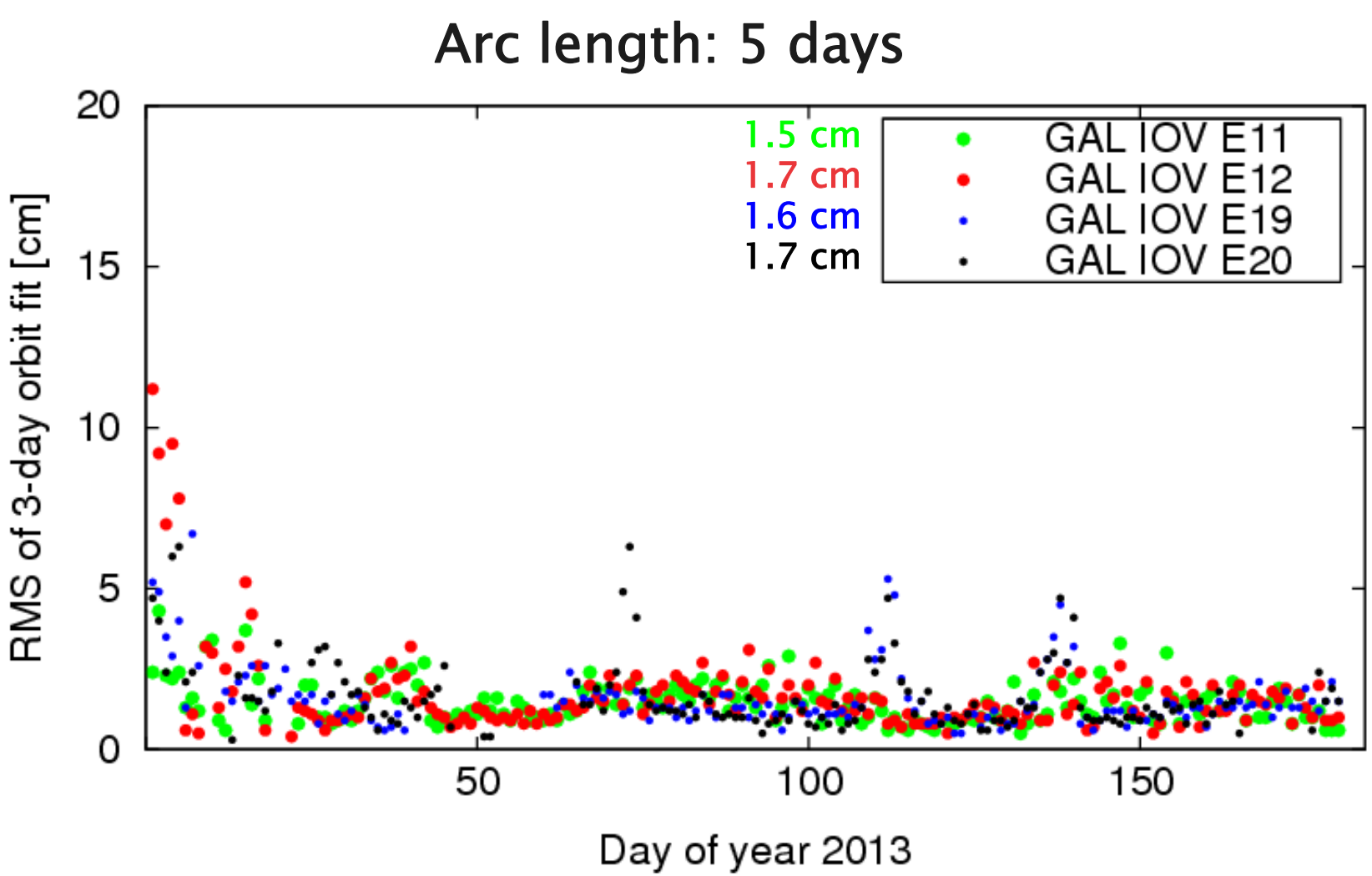
Orbit validation: three-day orbit fit



Orbit validation: three-day orbit fit



Orbit validation: three-day orbit fit



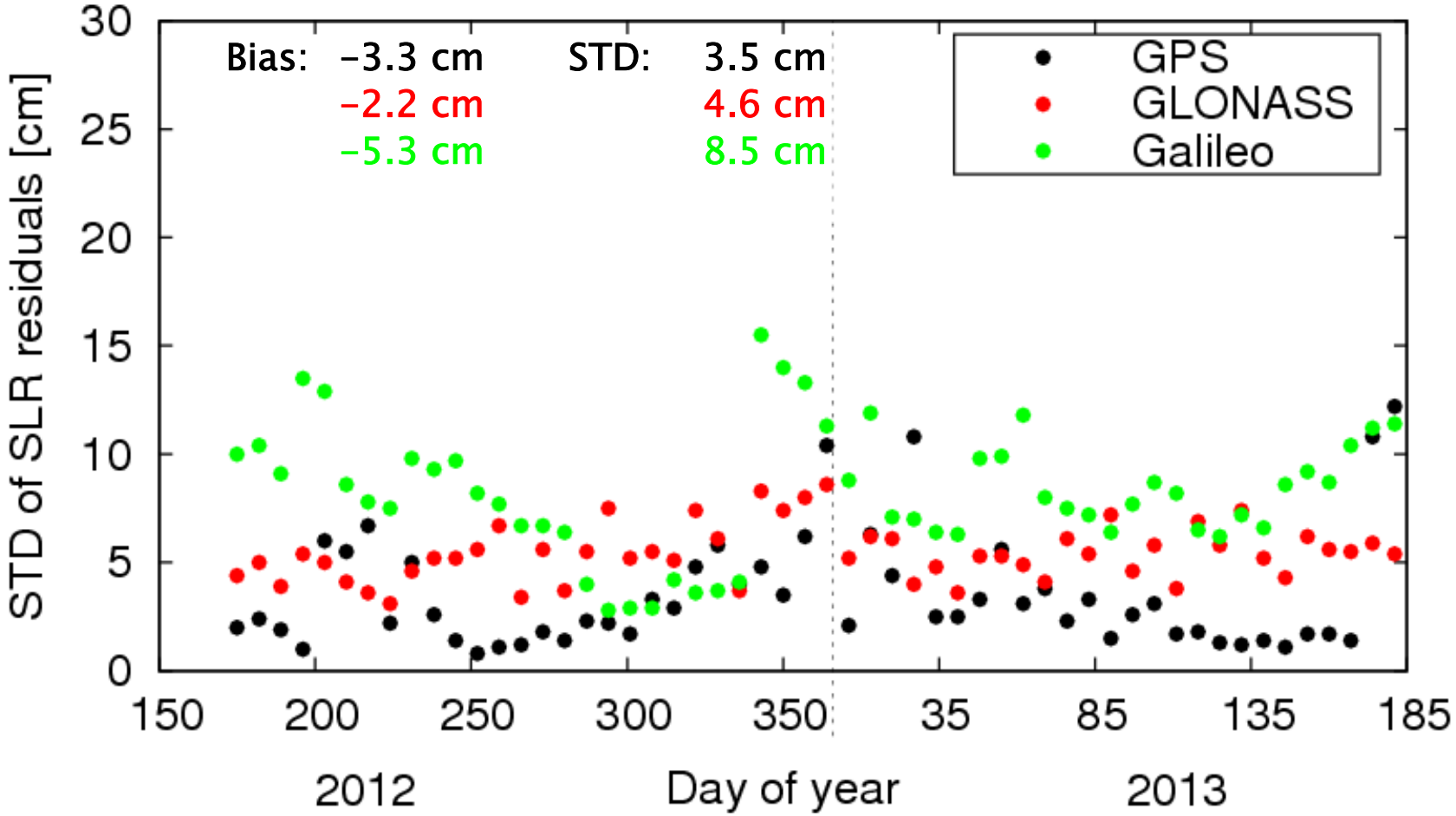
Orbit validation: SLR residuals

STD of SLR residuals per week and GNSS

Arc length	GPS	GLONASS	Galileo
1 day	3.5 cm	4.8 cm	9.6 cm
3 days	3.5 cm	4.6 cm	8.5 cm
5 days	3.6 cm	4.6 cm	9.4 cm

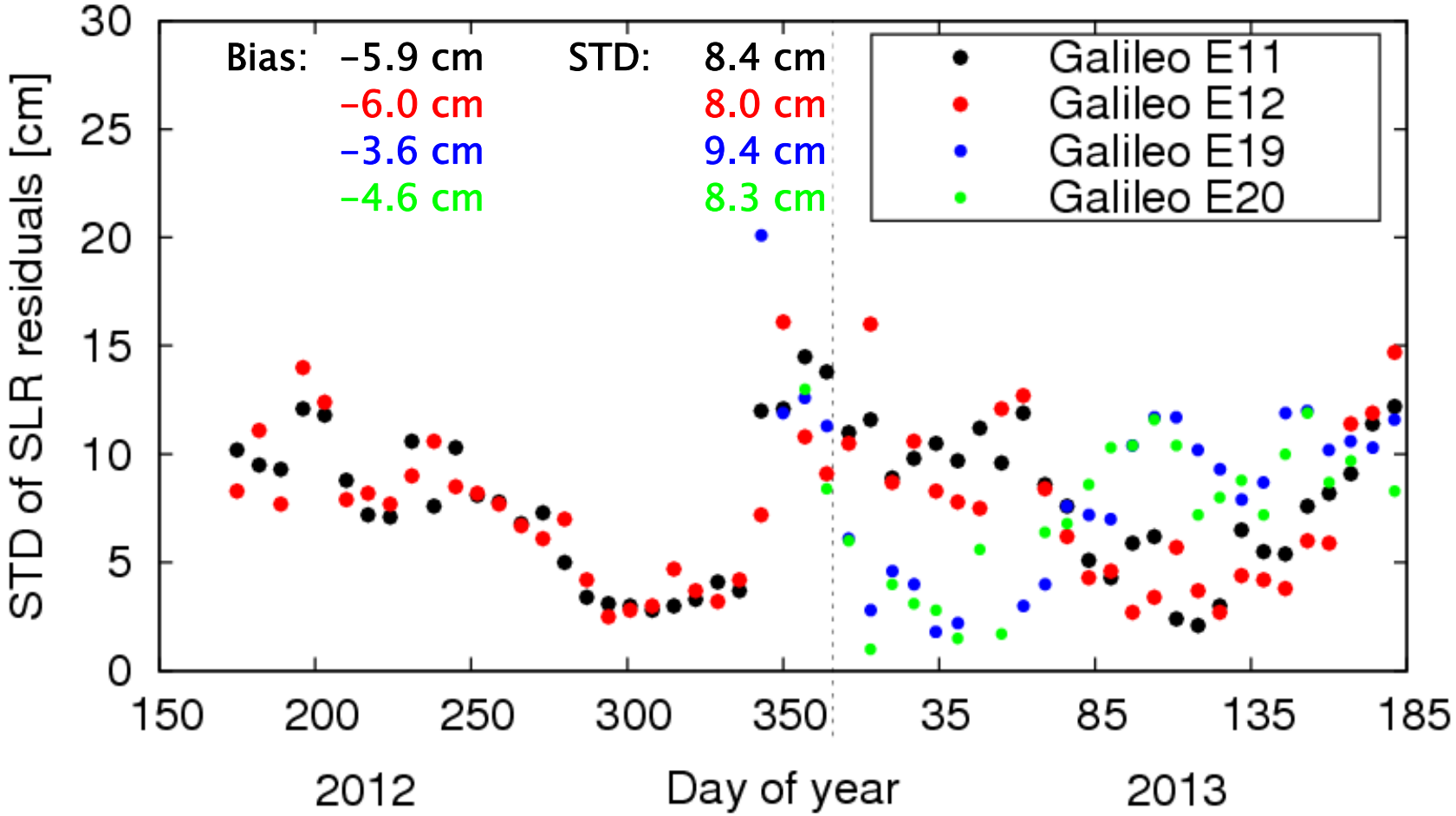
Orbit validation: SLR residuals

STD of SLR residuals per week: GNSS-wise



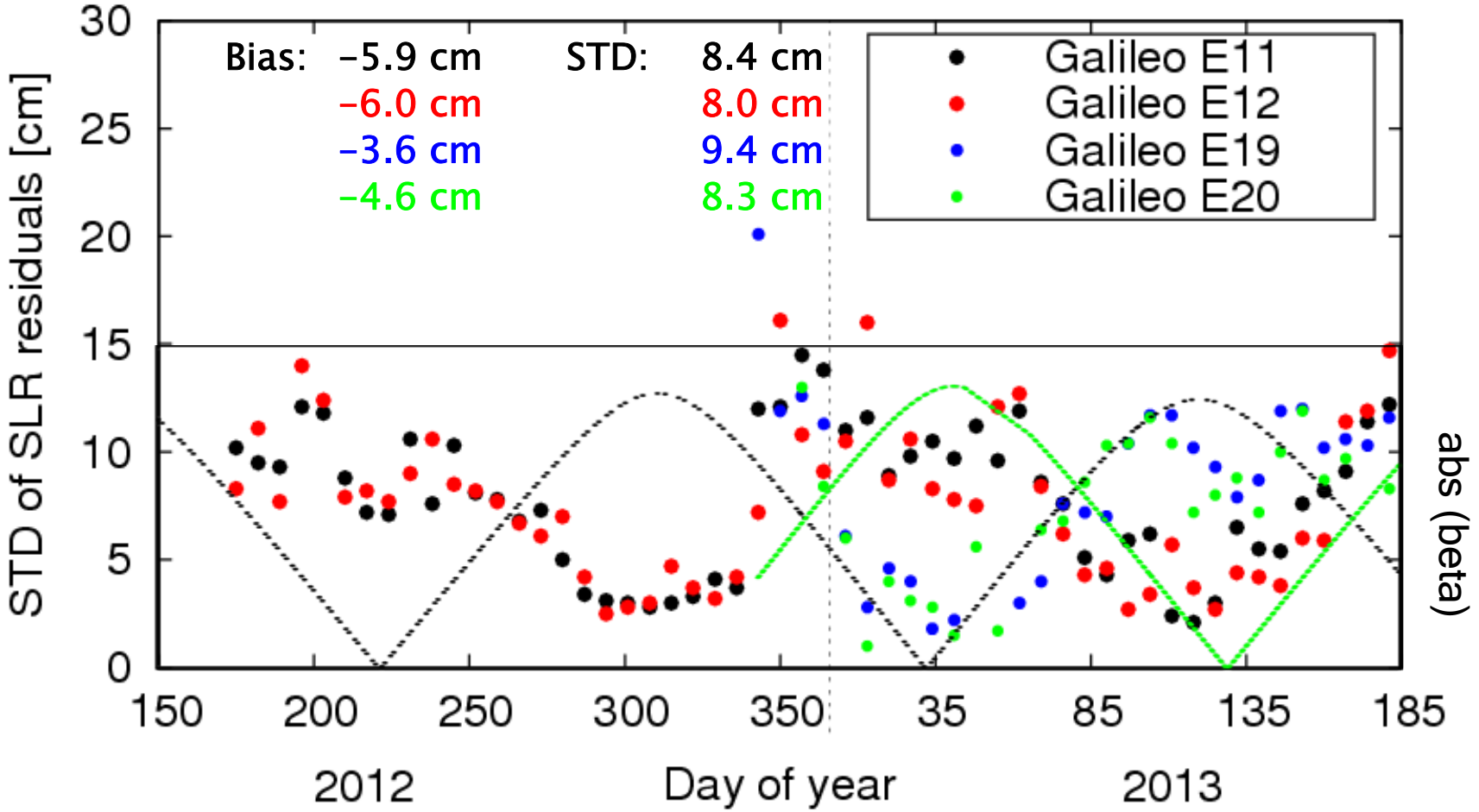
Orbit validation: SLR residuals

STD of SLR residuals per week: satellite-wise



Orbit validation: SLR residuals

STD of SLR residuals per week: satellite-wise

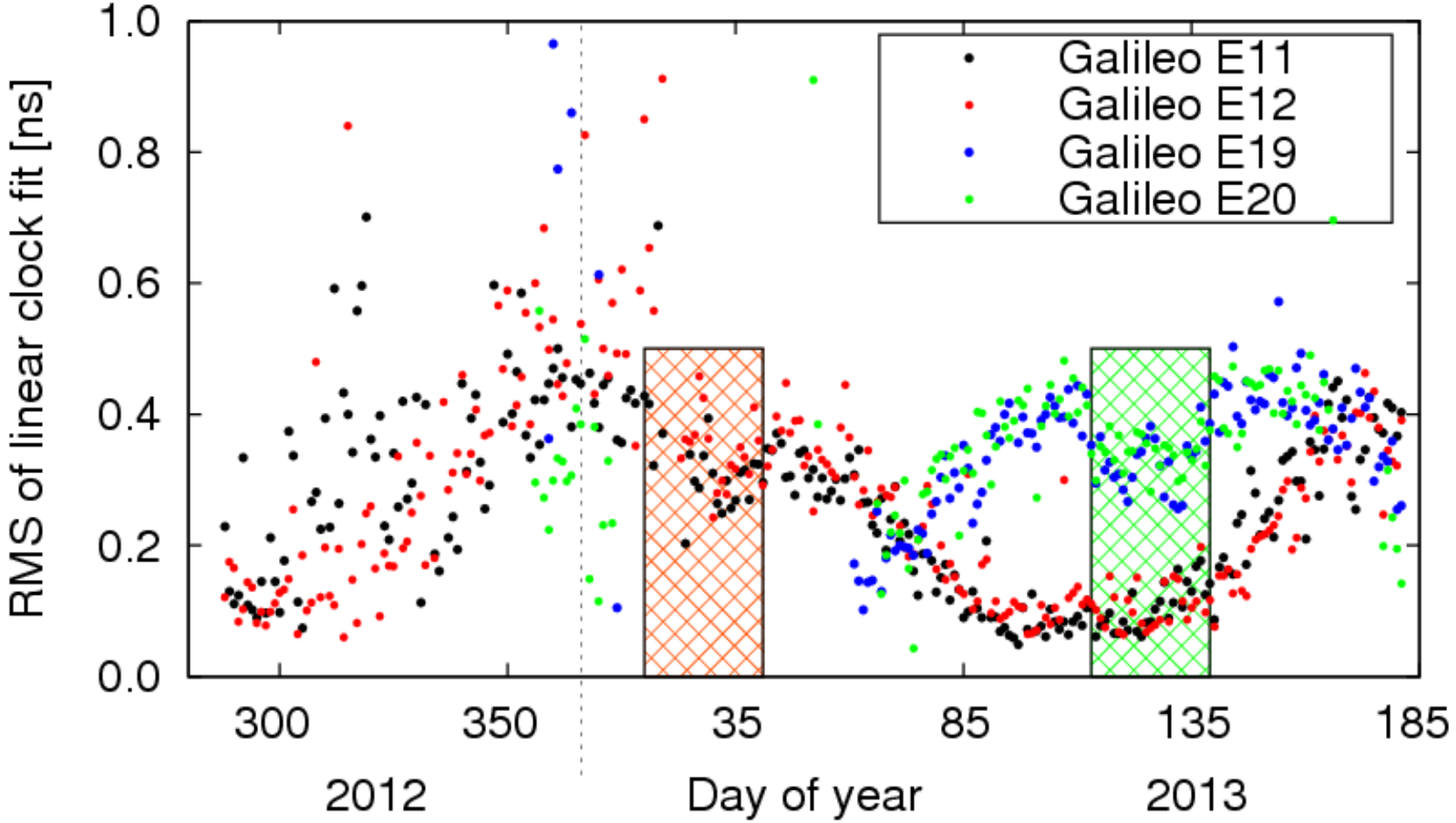


CODE MGEX clock solution: overview

GNSS considered:	GPS + Galileo (up to 36 satellites)
Timespan covered:	GPS-weeks 1710-1746 (DOY 12/288-13/180)
Number of stations:	150 (GPS), 30 -40 (Galileo)
Processing scheme:	zero-difference network processing (code+phase)
Signal frequencies:	L1+L2 (GPS); E1(L1)+E5a (L5) (Galileo)
A priori information:	orbits, ERPs, coordinates, and troposphere from CODE MGEX orbit solution introduced as known
Reference frame:	IGb08
IERS conventions:	IERS2010
Product list:	epoch-wise (300s) satellite and station clock corrections in daily clock RINEX files; daily GPS-Galileo inter-system biases for mixed stations in Bernese DCB and BIAS-SINEX (BIA) format
Distribution:	ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/
Designator:	comwwwwd.???.Z

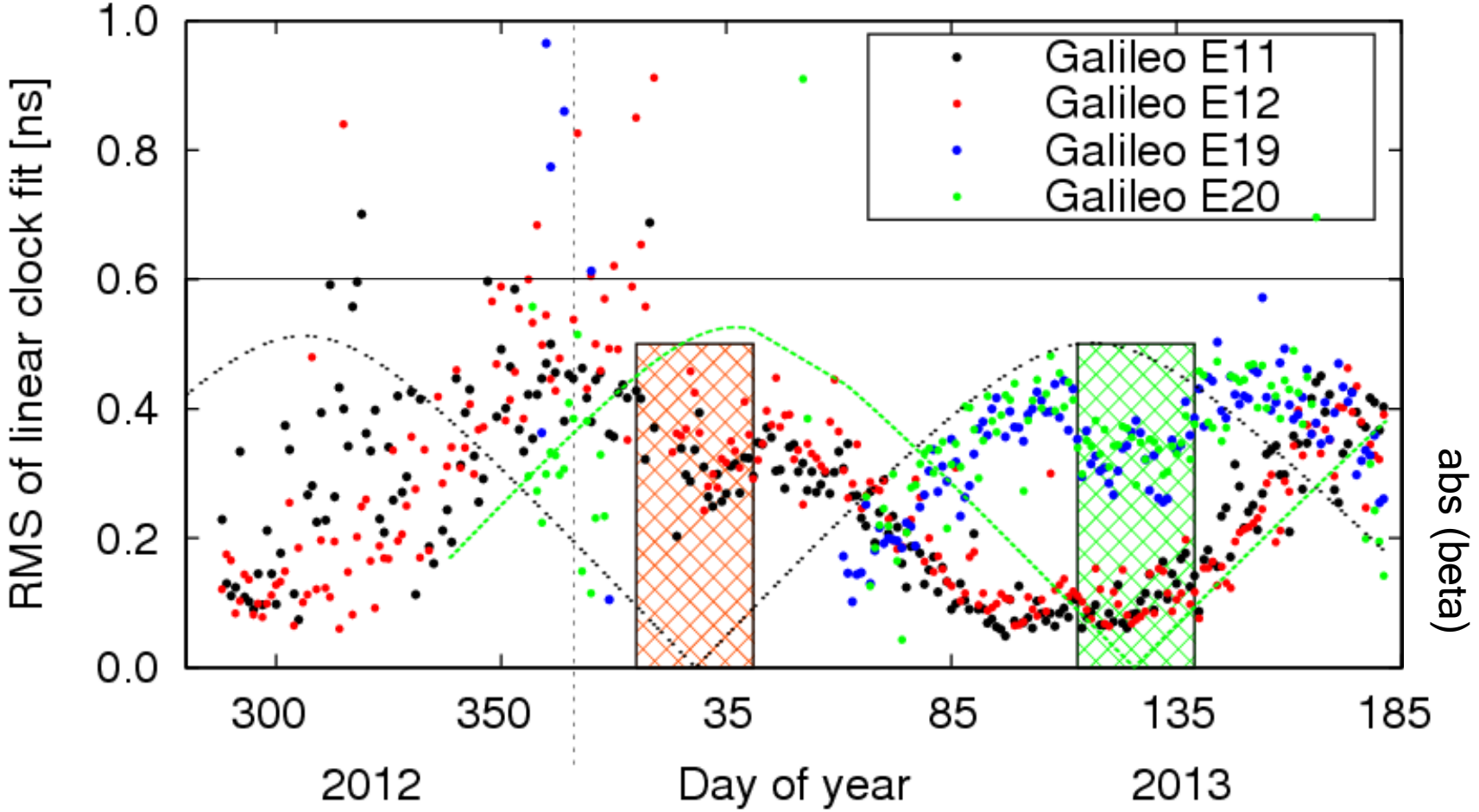
CODE MGEX clock solution

Galileo IOV: impact of sun eclipse



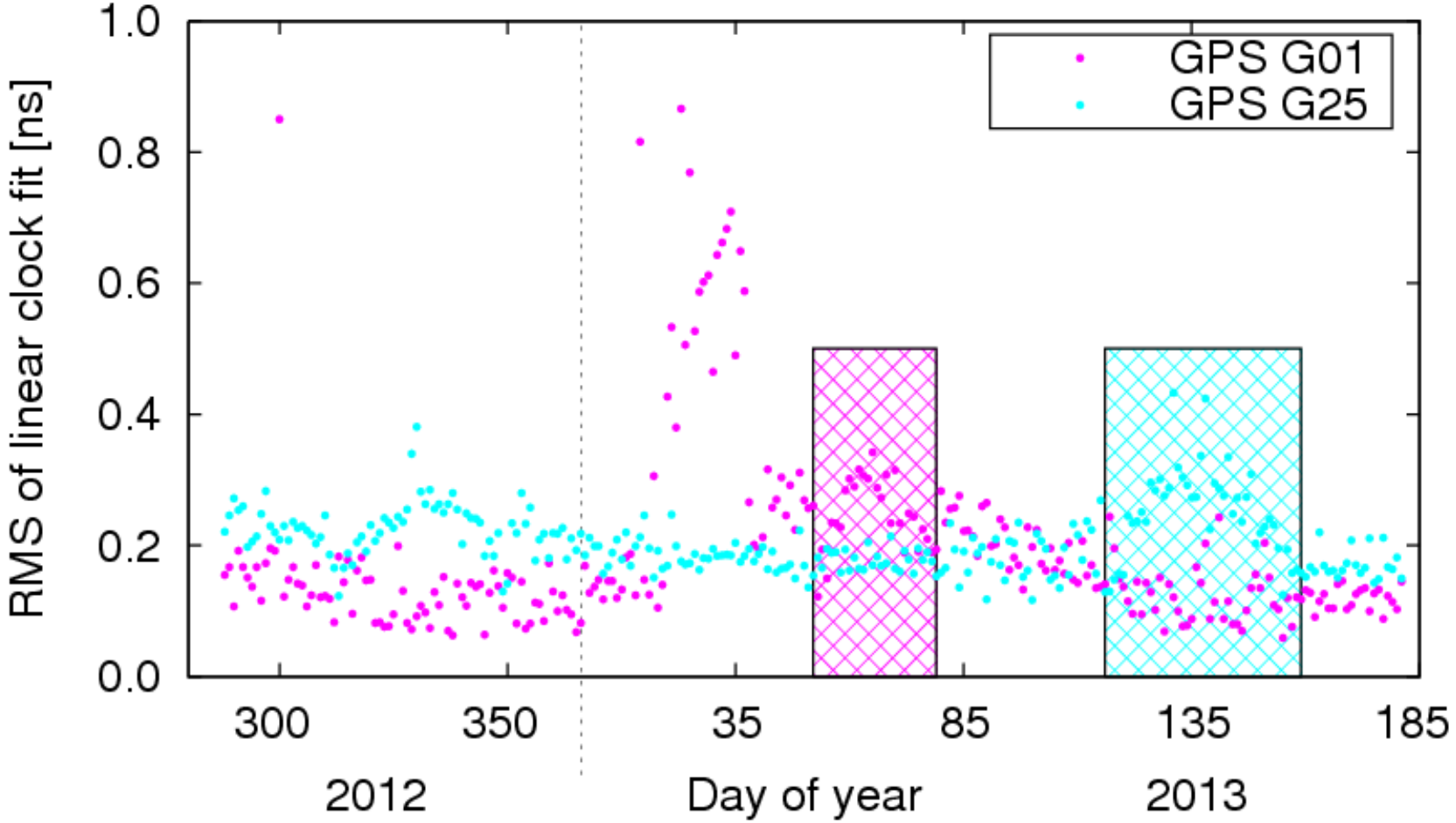
CODE MGEX clock solution

Galileo IOV: impact of sun eclipse



CODE MGEX clock solution

GPS-IIF: impact of sun eclipse



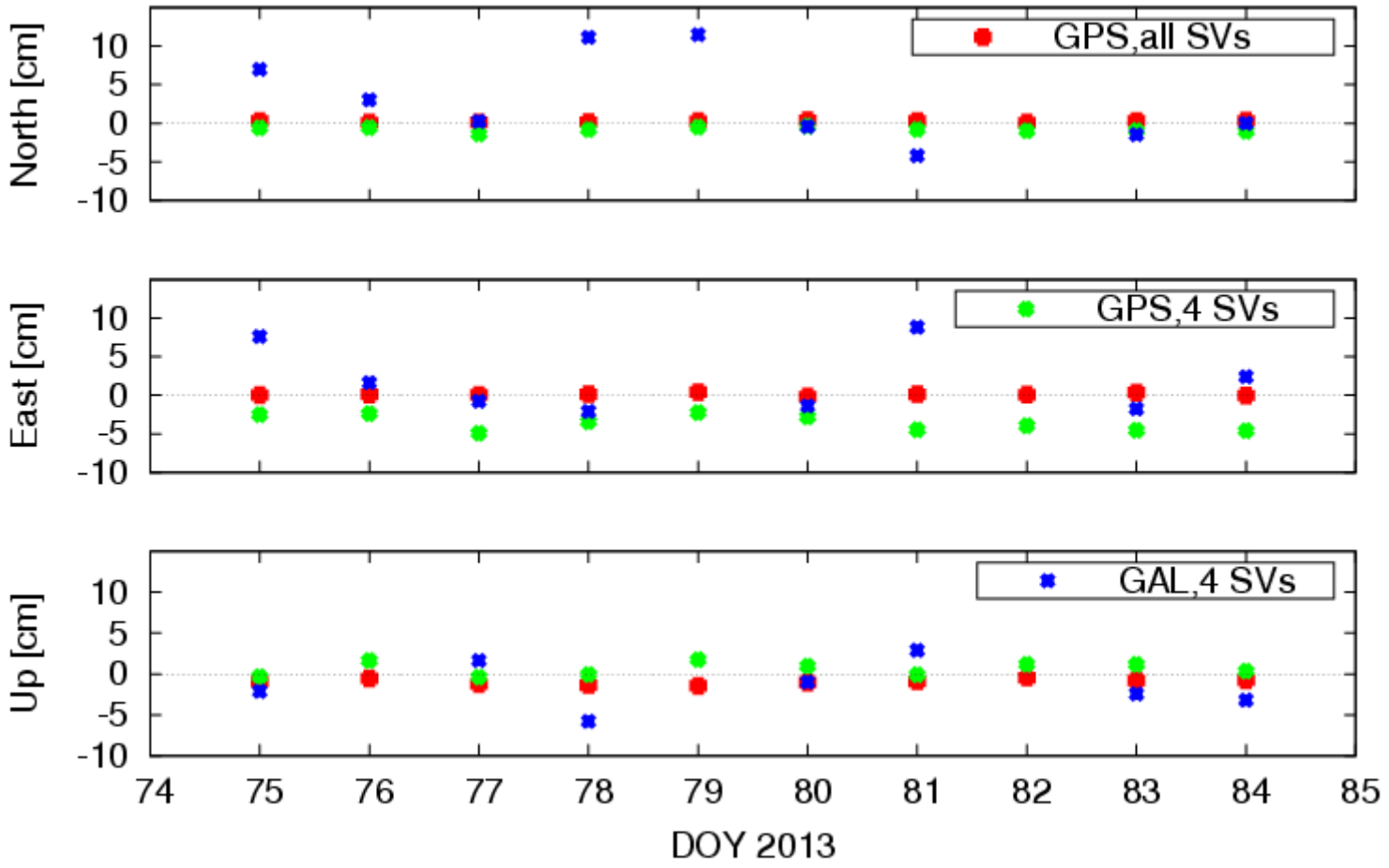
PPP, static mode (DOY 2013: 075 – 084)

Difference to CODE MGEX network solution (threshold 3 dm):
GPS+Galileo, GPS, GPS (4 SVs), Galileo

Station	North [mm]		East [mm]		Up [mm]	
	mean	STD	mean	STD	mean	STD
OUS2	3.7	1.7	-2.8	2.1	-8.6	6.0
	3.2	1.3	-1.1	2.0	9.3	6.0
	-11.9	24.0	-19.1	22.3	13.6	27.7
	37.9	135.6	33.8	34.4	-0.3	106.9
RIO2	1.7	1.2	-1.0	2.1	2.8	4.3
	1.9	1.2	1.6	2.0	3.2	3.7
	1.9	3.2	-30.4	21.0	18.2	19.4
	-27.2	62.7	-59.0	86.2	-9.7	50.8
TASH	0.3	1.1	2.8	2.4	1.9	4.1
	-0.4	0.8	1.2	2.0	3.4	4.4
	-3.6	13.1	-6.1	13.6	33.2	18.2
	-17.4	92.1	57.0	77.8	-43.3	101.3
ZIM3	2.4	1.3	2.9	1.9	-9.9	2.8
	2.5	1.0	1.0	1.7	-9.5	3.4
	-8.0	3.1	-36.0	10.4	6.1	8.2
	50.2	83.7	47.4	96.9	-65.9	91.9

PPP, static mode (DOY 2013: 075 – 084)

Difference to CODE MGEX network solution for station ZIM3:
GPS+Galileo, GPS, GPS (4 SVs), Galileo



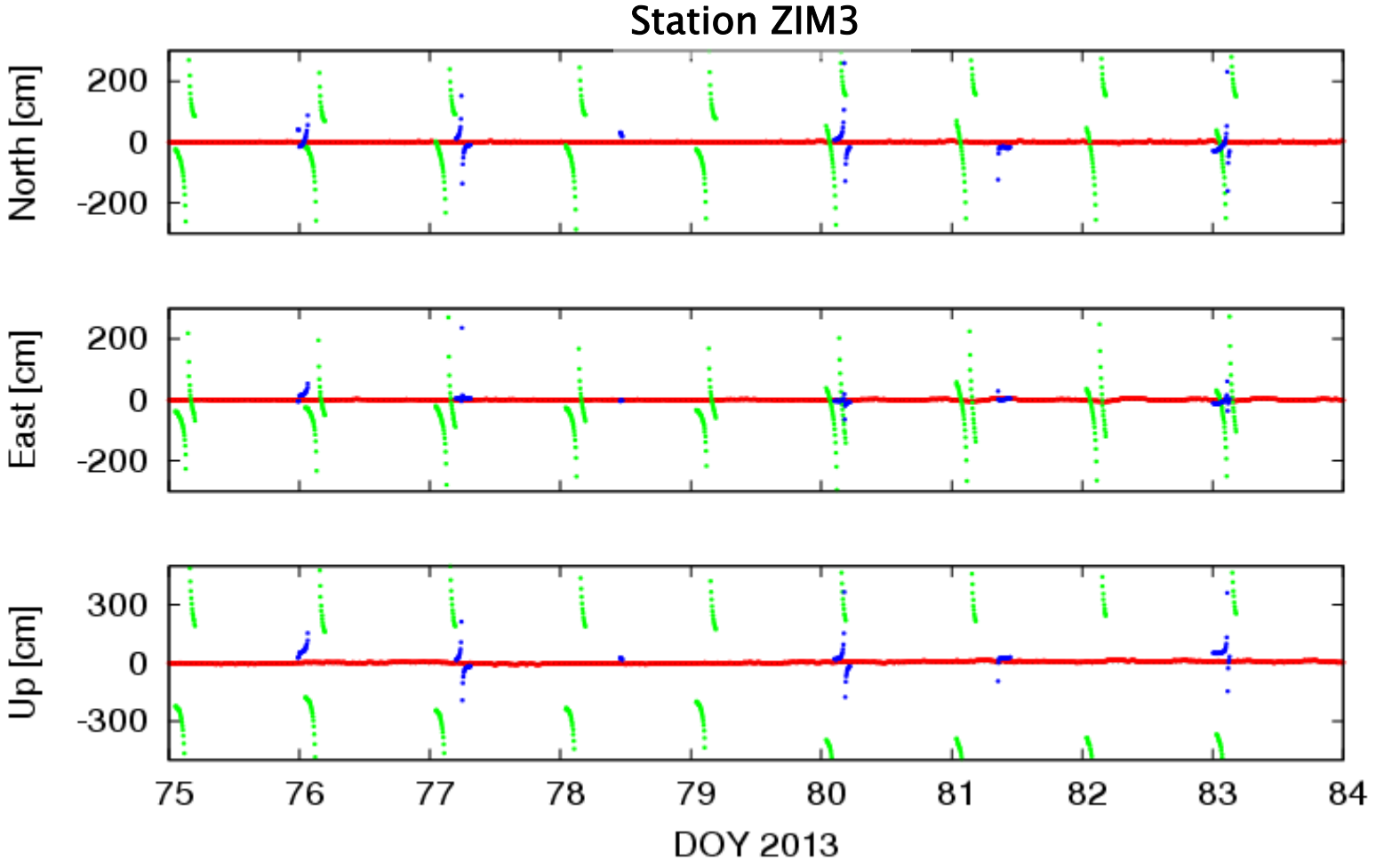
PPP, kinematic mode (DOY 2013: 075 – 084)

Difference to CODE MGEX network solution (threshold 1 m):
GPS+Galileo, GPS, GPS (4 SVs), Galileo

Station	North [mm]		East [mm]		Up [mm]	
	mean	STD	mean	STD	mean	STD
OUS2	3.0	33.0	-7.8	38.1	210.1	112.1
	2.5	38.6	-7.2	47.7	216.8	119.9
	-3132.4	2907.3	-3959.6	3819.2	5066.5	3375.5
	-104.6	1756.6	572.3	1036.7	-191.3	2251.3
RIO2	8.0	36.8	8.2	39.4	181.5	141.6
	7.8	43.9	12.2	47.5	185.7	149.0
	357.8	2034.4	63.0	901.1	557.2	4917.5
	-223.0	1283.7	-18.9	516.1	-549.8	1539.8
TASH	1.5	19.4	0.9	26.6	112.1	92.8
	1.1	21.6	-2.2	29.6	114.2	95.0
	2225.0	2677.2	-2679.8	3040.4	5133.4	3545.8
	-326.2	1229.5	270.9	741.1	-7.2	1393.7
ZIM3	3.0	12.5	3.5	16.5	30.0	54.2
	3.3	13.2	1.0	17.0	30.3	55.1
	265.0	2331.1	-360.0	1634.5	-1129.9	4364.2
	-112.2	690.3	13.8	369.2	246.7	944.6

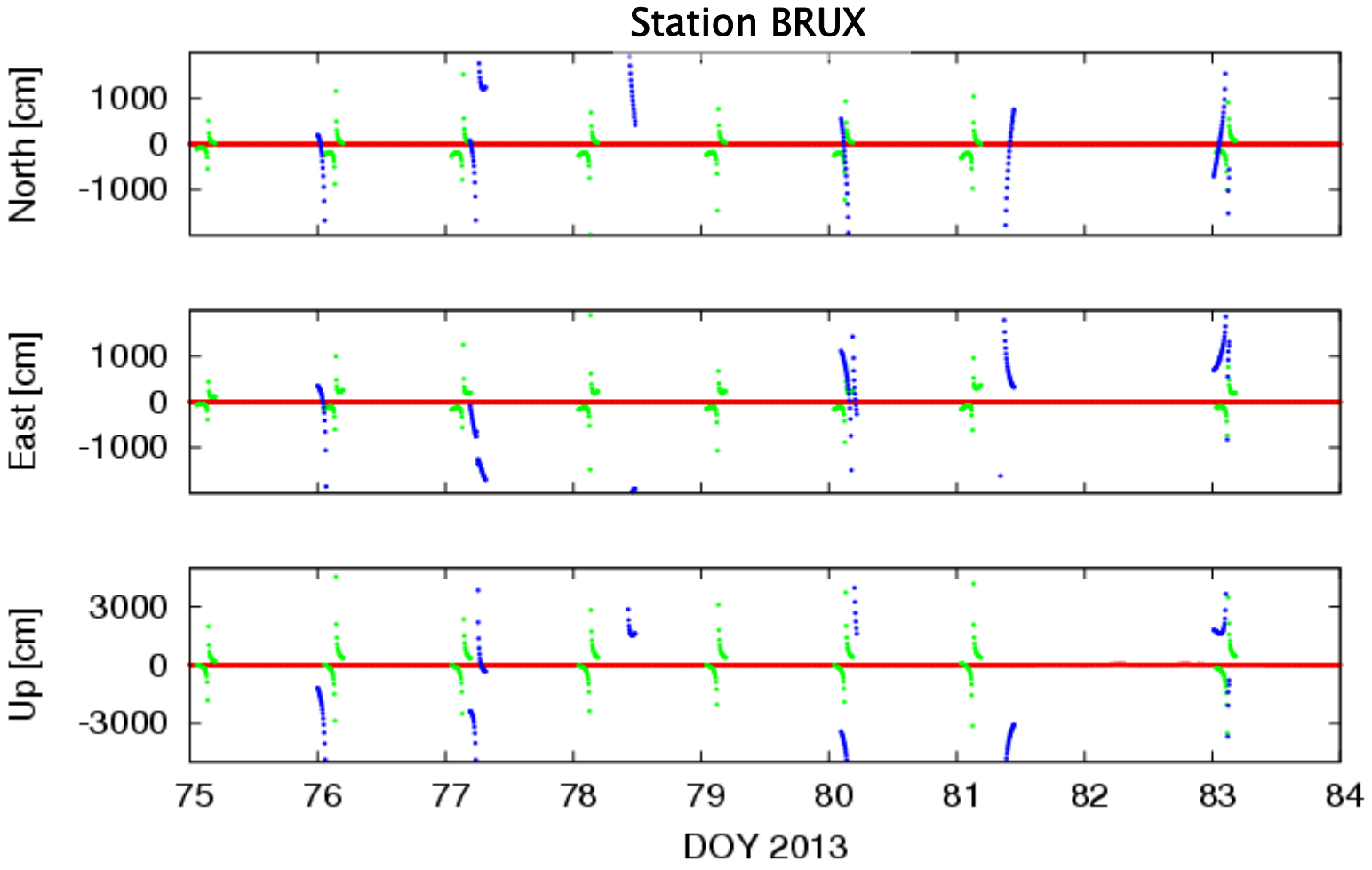
PPP, kinematic mode (DOY 2013: 075 – 084)

Difference to network solution: GPS, GPS (4 SVs), Galileo

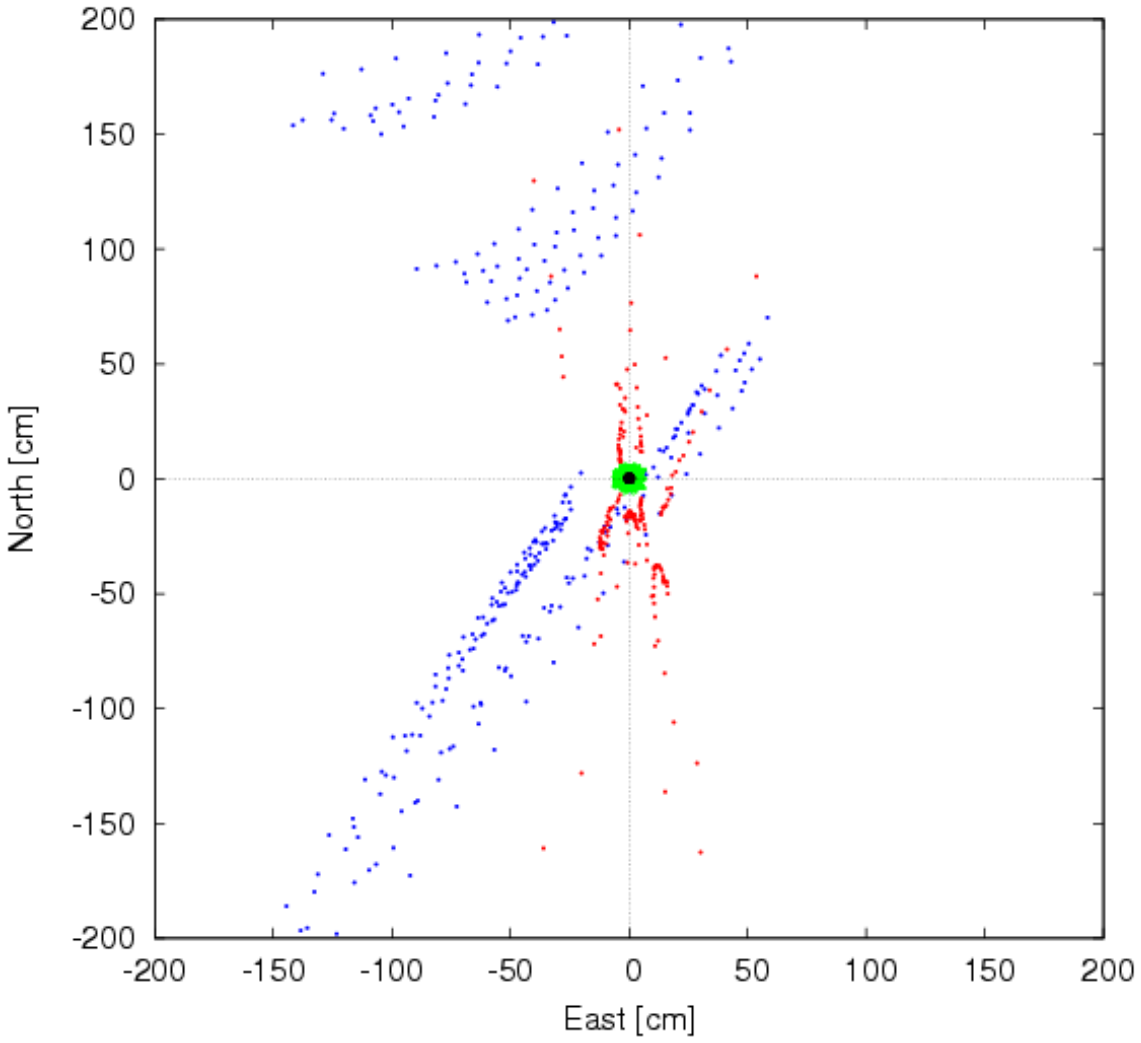


PPP, kinematic mode (DOY 2013: 075 – 084)

Difference to network solution: GPS, GPS (4 SVs), Galileo

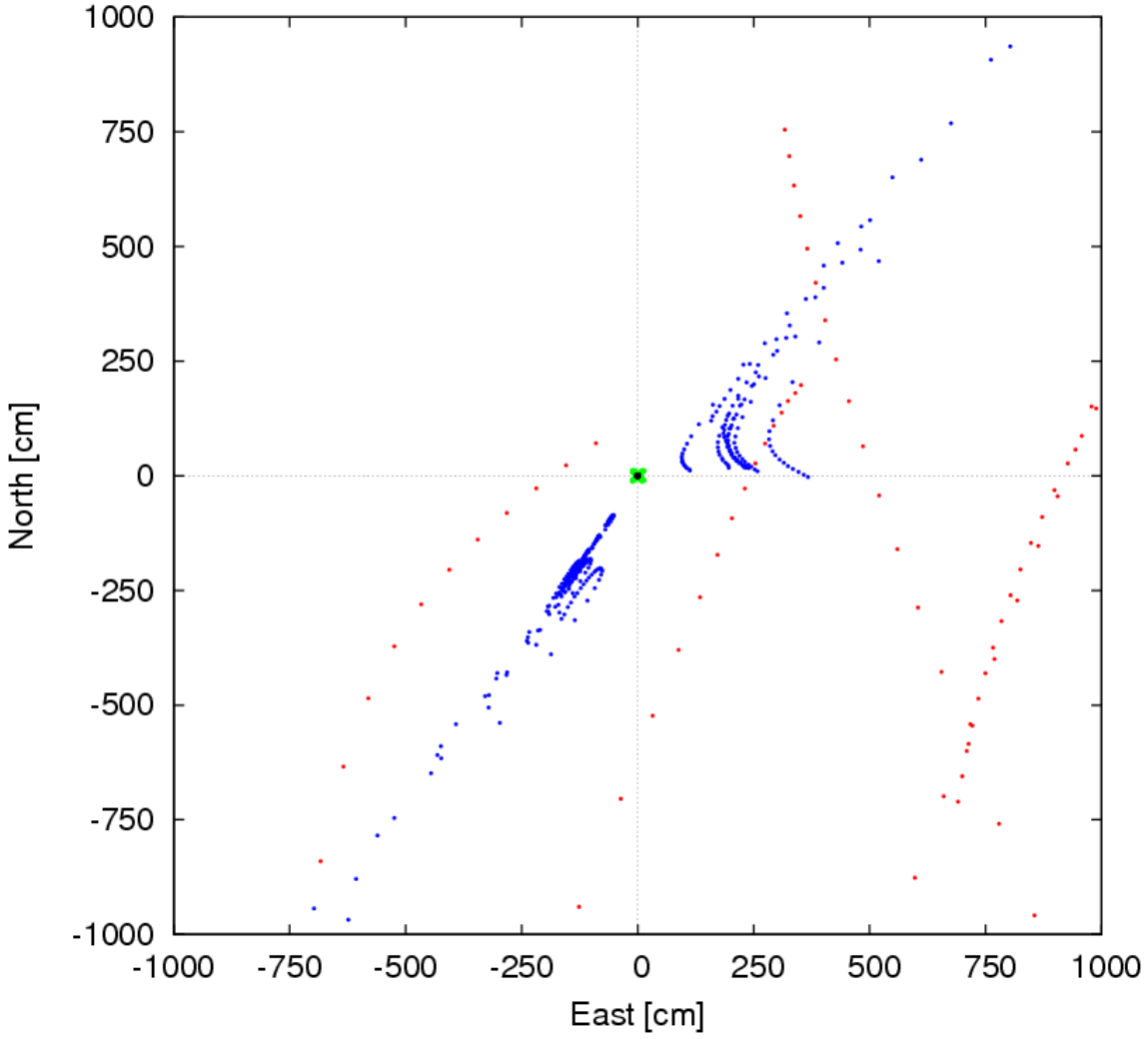


PPP, kinematic mode (DOY 2013: 075 - 084)



- Static
- Kinematic GPS
- Kinematic Galileo-only
- Kinematic GPS (4 SVs)

PPP, kinematic mode (DOY 2013: 075 - 084)



- Static
- Kinematic GPS
- Kinematic Galileo-only
- Kinematic GPS (4 SVs)

Summary

- The analysis of IGS MGEX data is very useful for understanding, integration, and exploitation of the new GNSS signals and systems.
- CODE provides a MGEX-based, fully integrated, triple-system orbit solution: GPS+GLONASS+Galileo
- Galileo orbits dramatically benefit from long arcs:
  - the inhomogeneous station distribution and
  - its long orbit revolution time (>>12h)
- CODE MGEX clock solutions are available and can be used even for a Galileo-only PPP.

Outlook

- Preparing the next batch for publication including GPS+GLONASS+Galileo+BeiDou+QZSS
- Preparation of an operational MGEX processing chain (at least for Galileo)
- Understanding of the orbit models for the new satellites (SNF-project just started)